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ILLUMINATION OF COAST GUARD VESSELS.

BY LIEUT. ROBERT T. ALEXANDER, U. S. C. G.

The author discusses various considerations involved in obtaining good illumination on small vessels of the types used in the Coast Guard.

On large passenger vessels a considerable proportion of the lighting installation follows in general illumination practice in hotels and clubs which is well discussed in the literature of illumination. Little has been published regarding the illumination of non-passenger carrying vessels either in journals of naval architecture or journals of illuminating engineering. Several excellent articles on Naval illumination practice exist, but these are principally concerned with vessels of 10,000 tons and upwards.

In this study it is proposed to inquire into illumination of Coast Guard vessels of between 300 and 2000 tons displacement. With the exception of certain military requirements, this discussion

should be equally applicable to commercial vessels not engaged in passenger trade.

General Requirements for Good Illumination.

Excluding signal lights, the purpose of all lighting on ships of the class under consideration is to allow individuals to see. Thus, major considerations of any installation are: (1) the quantity or intensity of illumination necessary to allow individuals to perform assigned tasks efficiently; (2) quality of illumination under actual service conditions.

Illumination Levels.

The human eye can adapt itself to a wide range of luminosity. It can see under levels of illumination from 10,000 foot candles to .01 foot candle. This is a range of 1,000,000 to 1. Determination of the level at which the eye can perform a given visual task with a minimum of fatigue, in the minimum time and with the least number of errors, is an exceedingly complex problem.

Some of the information regarding illuminations levels is no doubt influenced by the desire to sell more electrical power. On the other hand, investigations have shown that as the illumination is increased, the ease and speed with which a visual task is performed are increased. These tests have not established an upper limit but have established levels below which harmful effects are present.

In illumination practice in industry the lower limits of illumination, that is, levels at which a balance is attained between the cost of harmful effects such as slower production, accidents, errors, and the cost of illumination, are set forth in "Recommended Practice for Industrial Lighting" by the Illuminating Engineering Society. These standards are the most trustworthy available by reason of being subject to criticism by disinterested authorities on illumination.

In marine lighting installations in non-passenger carrying vessels two sets of standards exist. They are: "Navy Standards" and "Recommended Practice for Electrical Installations on Shipboard" (1938), written by the American Institute of Electrical Engineers.

These latter standards purport to give recommended minimum levels of illumination by stating minimum watts per cubic foot. Standards of this type were abandoned by illuminating engineers about 1900. They bear about the same relation to actual levels of illumination as a table of horsepower as a function of heighth of mast would give in determining the installation of propelling machinery. While recent tables have included factors for direct, semi-direct, and indirect lighting, they remain inadequate standards of illumination. Consider just one aspect of such a standard, namely, efficiency of the light source. Mazda sources in common marine use vary from 10.6 lumens per watt for 25-watt lamps at rated voltage to 17.7 lumens per watt for 100-watt lamps. Gas discharge lamps of various types now available give from 25 to 40 lumens per watt. Clearly, standards set forth in terms of watts per cubic foot can give only the very roughest indication of illumination level.

Navy standards are stated in the same terms as the industrial standards, namely, minimum levels of illumination for places where specific visual tasks are performed. In general, minimum levels in the Navy standards are lower than in industrial practice although since 1935 the gap between the two standards has been steadily growing smaller.

From Table IA it can be seen that levels of illumination in marine standards are lower than in industrial practice (even latest Navy standards while higher than given in the preceding table are below industrial practice). The question arises, "Are these lower standards justified (*a*) from any difference in visual tasks on shipboard, (*b*) from electric power available for lighting marine installations?"

Aside from those persons whose duties at night may be classed, in a very broad manner, as lookout and whose visual tasks involve dark adaption of the eye, all of the other visual tasks are more or less similar to tasks found in industry. The principal difference on smaller vessels (2000 tons and less) is that quite often these tasks are made more difficult by vibrations and motions of the ship as a unit. Vibrations due to propelling and auxiliary machinery and to impact with waves make seeing more difficult. Recent in-

TABLE IA.

MINIMUM ILLUMINATION LEVELS.

FOOT CANDLES ON WORKING PLANE.

Compartment	*Industrial Practice 1939 Comparable Cases (1)*	*Navy 1935 (2)*	*Navy 1916 (3)*	*AIEE Marine Standards 1938 Computed (4)*
Washroom	5	3	1.0	2.4
Galley	20	3	2.0	2.4
Cabin	15	6	3.0	2.4
Machinery Space	10	5	1.5	2.4
Wardroom	10	6	2.5	2.4
Stateroom	10	3	3.0	2.4
Machine Shop	20	10	1.0	2.4
Office, general illumination	20	5	4.0	2.4
Living Space, crew	10	3	1.5	2.4
Passageways	5			1.3
Desk work	20			
Reading positions	20			
Holds, Storerooms	5			1.3

(1) Illuminating Engineering Society, "Recommended Practice of Industrial Lighting, 1939."

(2) T. E. Cassey, "Illumination of Naval Vessels." JOUR. AMER. SOC. NAVAL ENGINEERS, 1935, Vol. 47, No. 4, p. 499.

(3) Lieut. C. S. McDowell, U. S. N., "Illumination in the Navy," Trans., I. E. S., Vol. XI, p. 573.

(4) Computed from American Institute of Electrical Engineers Standard No. 45, "Recommended Practice for Electrical Installations on Shipboard." For direct illumination assuming bare mazda bulb, 4 feet above working plane, unit volume $6 \times 6 \times 7$ feet high. Value given is maximum illumination, directly under lamp assuming uniform spherical distribution of candle power of bulb.

vestigations in connection with lighting of trains and buses have shown the need for higher levels of illumination for the same task when vibration is present. The motion of the ship as a unit should call for much higher levels of light in passageways, wash rooms, store rooms, and general living spaces if a degree of safety comparable to shore practice is to be achieved. The smaller the vessel the more attention should be given to this aspect of marine illumination.

The tasks which involve dark adaptation of the eye are most important from a standpoint of safety to the entire ship and the efficiency of her operation whether naval or commercial. To evaluate the effect that higher illumination levels might have on the performance of lookout duties a brief consideration of the phenomena of dark adaption of the human eye is in order. It is well known that when a person goes from a lighted space to a dark space a period of time elapses before the eye becomes adapted to the much lower level of illumination, and can perceive areas of very low luminosity such as distant lights. This phenomena has been investigated by Hecht, Helmholtz and others.

It is commonly thought that the contraction of the pupil allows the eye to see under the wider range of luminosity mentioned above. Actual measurements show that under a variation of luminosity of 1,000,000 to 1 the area of the pupil varies only from 16 to 1. This shows that the change in diameter of the pupil has only a very limited effect in adapting the eye to large changes in luminosity. It is now believed that the retina of the eye is a complex structure of microscopic nerve terminals of two types called rods and cones. As one goes further from the center of the retina the proportion of cones diminishes and the proportion of rods increases. The cones are insentitive to very weak light, but respond to moderate and high intensities and produce color sensations in the brain. The rods, on the other hand, respond to very low intensities, but do not produce color sensations.

In all ordinary visual tasks the sensations of sight and color are transmitted to the brain by the cones. This type of vision is known as photopic and extends down to the levels of .01 lumens per square foot. Vision where sensations of sight are transmitted

by the rods alone is called scotopic or night vision. Objects having a luminosity less than .001 lumen per square foot are perceived by scotopic vision. Between .01 lumen per square foot and .001 lumens per square foot both rods and cones are active. Thus when an officer or man goes on night watch his seeing undergoes a transition from photopic to scotopic vision. Because of the lack of color sensitivity of the rods, in night vision the eye becomes more sensitive to blue and violet light and almost blind to low intensities of red light. Since there are more rods in the area away from the center of the retina the well known practice of looking out the corner of the eye to pick up weak lights is justified because such practice focuses the image on that part of the retina most sensitive to low luminosities.

The transition from photopic to night vision is a very gradual process. Various investigations have shown that the time taken for the eye to reach its maximum sensitivity in the dark is of the order of one hour. If the luminosity of the weakest light perceptible to the observer is plotted as ordinate, and the time the eye has been in darkness as abscissa, it is found that the relation between time and sensitivity is an exponential one. Thus although the time taken to reach maximum sensitivity may be one hour the eye may reach 75 per cent of its maximum dark sensitivity in 10 minutes and 90 per cent in 15 minutes. Different investigators have chosen various levels of illumination of the order of 10 to 80-foot candles at which the eye was allowed to adapt itself to light before being placed in darkness and the resulting curves of dark adaptation are closely similar, leading to the belief that differences between individuals are probably of the same order as the difference in the time required to reach 75 per cent of maximum dark sensitivity from 5-foot candles and the time required to reach the same sensitivity from 20-foot candles. Even if further investigation does reveal that there is a systematic increase in the time required for dark adaptation, as the level to which the eye was light adapted is increased, evidence already at hand shows that this difference will probably be of the order of seconds in a process whose total time from the practical aspect (time to reach 75 to 90 per cent of maximum sensitivity) is from

ten to fifteen minutes. Certainly the importance of this small time difference, if it exists, is not of itself great enough to require lower levels of illumination on shipboard than in industry. Since the eye may become light adapted in less than a minute, a short glance at the chart is followed by a ten or fifteen-minute period of partial blindness to objects of low luminosity. Good seamen are cautious in their use of light at night and try to preserve the condition of dark adaptation for a high percentage of the time on watch.

Thus from a consideration solely of visual tasks performed it seems desirable that marine illumination levels on small vessels should be slightly higher than those used in industrial practice.

The statement is often made that marine illumination levels must be lower than those of industrial practice because of limitations of amount of electric power available on shipboard. In analyzing this statement, the fact that higher illumination may be achieved with the same power consumption by use of more efficient sources of light will be neglected and the assumption made that present tungsten lamps are used and that higher levels of illumination will require more power.

Consider first the original design of the generator installation. The designer of the machinery installation must reach a compromise with weight, space and cost in determining the total generator capacity. The relation of the lighting load to the total electrical load depends principally on two variables, the size of the vessel and level of illumination to be provided in various compartments.

On the small patrol boat and picket boat the lighting load approaches 100 per cent of the total electrical load. As the size of the vessel increases the lighting load becomes the smaller part of the total electrical load. On the 1000-ton, 165-foot *Escanaba* class of Coast Guard cutter the average peak lighting load was found to be 31 per cent of the average peak electrical load. On the 2000-ton, 250-foot *Cayuga* class the average peak lighting load was 17 per cent of the average peak auxiliary electrical load at sea and 60 per cent of the average peak auxiliary load in port. On the 2000-ton, 328-foot *Bibb* class cutter the average peak lighting load was 24 per cent of the average peak load at sea and 36 per cent of

average peak load in port. The data obtained from these three vessels shows that the average peak lighting load corresponds very closely to 75 per cent of the maximum lighting load.

Photometric data as to the levels of illumination provided for these lighting loads is available only for the *Escanaba*. It can be said that the levels of illumination were somewhat higher than 1935 Navy practice, lower than 1938 Navy practice and lower than 1939 industrial practice. To raise illumination to industrial levels would increase lighting load about 75 per cent, making lighting load about 45 per cent of total electrical load. The *Escanaba's* illumination levels are believed to be higher than the average Coast Guard vessel excepting the *Bibb* class. It is probable that to adopt industrial standards of illumination would in general double *present* lighting loads on most Coast Guard vessels excepting the Lighthouse Tenders. On this latter class a rough survey of the *Walnut* indicated that to reach industrial standards the lighting load would be increased four to five times that in use at present.

It is interesting to examine the percentage increase in generator capacity which adoption of industrial levels of illumination would entail (assuming that industrial levels would double lighting load). On the *Escanaba* class a 20 per cent increase in capacity of each auxiliary generator would be required to take care of increased lighting load. On the *Cayuga* type a 9 per cent increase would suffice. On the *Bibb* class a 10 per cent increase should be sufficient. On the Lighthouse Tender *Walnut* a 120 per cent increase would be needed. Whether limitations of weight and space would make these rather moderate increases impracticable only the designer himself can say, but certainly the increases required in most cases are not so large as to make consideration of industrial levels of illumination on Coast Guard vessels impossible.

How far illumination levels may be raised on units already built depends upon the amount of reserve generator capacity which may safely be used for lighting. Modern Coast Guard vessels have been designed with very adequate reserve generator capacities. If they had not, illumination levels would be much lower than now found in service. Examination of the design maximum lighting load and present lighting load of the *Escanaba* and *Cayuga* shows that present maximum lighting load is somewhat over twice the

load called for when commissioned. It is believed that further investigation of units which have been in commission for six years or more would show that personnel have found it desirable to up levels of illumination so that original lighting load has at least been doubled. The amount of reserve capacity still available is shown in Table I.

TABLE I.

RELATIONS OF LIGHTING LOAD AND GENERATOR CAPACITY.

Vessel	*Capacity of Generator in Use*	*Average Total Peak Load Kilowatts*	*Per Cent Capacity in Use at Average Peak Load*	*Design Maximum Lighting Load Kilowatts**	*Actual Maximum Lighting Lad Kilowatts*
Escanaba					
At sea	35 KW	26.4	76	4.0	9.2
In port	35 KW	24	69		
Cayuga					
At sea	187.5 KVA	35	18	7.5	16.0
In port	62.5 KVA	20	32	7.5	16.0
Bibb					
At sea	300 KVA	92.6	31		29
In port	300 KVA	61.3	21		29
Walnut	12.5 KW				5.0†

* Based on specifications for original lighting installation. Data from engineer officers show average peak lighting load is very close to 75 per cent of maximum lighting load.
† Estimated.

From this it is apparent that further increases in the lighting load on the *Escanaba* would be impracticable, but on the larger units it could be increased without great difficulty.

If reserve generator capacity is available on shipboard the cost of the increased power is less than the cost of increased lighting load ashore. Engineer officers of various Coast Guard units have computed the fuel cost of increased load from auxiliary generators as follows: *Bibb*, .027 per Kwh.; *Cayuga*, .02; *Escanaba*, .034; compared with an average of .04 per Kwh. for power in small industrial installations.

Thus it is seen that the limitation of power supply while very real in the marine installation and while in some cases may require lower illumination levels does not make impossible or impracticable the use of industrial levels on a large number of Coast Guard vessels.

It will be shown later that the use of more efficient sources of light would make the actual increase in generator capacity needed to provide industrial illumination levels less than the amounts estimated above.

It is believed that at the present time Navy minimum illumination levels should be adopted by all units with adequate generator capacity. If the trend of the past four years continues it seems logical to believe that Navy levels will in the next few years equal industrial levels. In the design of new units it would seem desirable to allow for a lighting load sufficient to provide industrial levels of illumination. This would call for a design lighting load approximately four times that used in ships constructed in 1931-32 and about five times the present commercial practice in non-passenger vessels.

Quality of Illumination.

The intensity of illumination, while it may be rather easily measured and standardized, is far from being the sole criterion of good illumination. Of at least equal importance is the quality of the light furnished. So many factors enter into the consideration of quality of illumination that measurement and standardization are close to impossible. While considerable progress has been made in the adoption of higher levels of illumination on shipboard, the quality of shipboard lighting in small vessels has had surprisingly little improvement since the introduction of the electric lamp.

Important factors in determining the quality of a marine illumination system are: (1) Light evenly distributed on objects to be seen; (2) Glare; (3) Shadows; (4) Contrast; (5) Color; (6) Reliability; (7) Efficiency; (8) Appearance.

Special factors which make it more difficult to obtain comparable quality of illumination in small vessels are: (1) Low ceiling height (7 to 7½ feet on Coast Guard vessel studied); (2) Ceiling

spaces broken up by beams, pipes, ventilating ducts and cables; (3) Requirements of water tightness in certain fixtures; (4) Vibration and movement of ship; (5) Small irregular shaped compartments; (6) Desirability of having as few different types of fixtures as possible.

The single factor that has most discouraged improvements of quality of illumination in small vessels has been the accepted practice of using water-tight fixtures in all compartments for general illumination. The principal consideration of the manufacturers of water-tight fixtures has been that the fixtures be rugged and water-tight. Outside of recent Navy designs, no attempt is made to control direction of illumination and, since single etched glass is almost the sole diffusing material in use at present, the diffusion is only partial and almost all water-tight fixtures obtained from commercial sources have optical characteristics that differ but slightly from a bare Mazda lamp.

It is somewhat difficult to see the logic of using water-tight fixtures affixed to the ceilings of inside compartments above the waterline and then on the same circuit permitting non-water-tight desk lights, shaving lights nearer the waterline and finally installing non-water-tight convenience outlets at the waterline. Certainly the emergency lighting circuits should be completely water-tight. All deck fixtures and the fixtures in certain compartments such as the machinery spaces, compartments below the waterline, showers, etc., should be water-tight. In other compartments such as crew space, ships office, wardroom, etc., non-water-tight fixtures could well be used with a considerable saving in cost. It is true that this would entail more different types of fixtures than are at present installed when the vessel is commissioned, but it is believed that by careful standardization of suitable non-water-tight fixtures the number of different types of fixtures in actual use would be materially reduced. The present practice where each change of personnel sees new additions to the lighting equipment without regard to previous installations is making many of our vessels assume the appearance of a display shop for lighting fixtures.

Thus the first step in improving the quality of illumination on Coast Guard vessels would be the adoption of specifications similar to those contained in Navy General Specifications for Machinery,

Subsection S62-3-e-f-g, outlining where water-tight and non-water-tight fixtures should be used.

With this outline the design of lighting systems to provide improved quality of illumination and yet meet the special requirements found on small vessels could proceed in a more orderly fashion and give better illumination at less cost.

Consider now the effect of special factors encountered on small vessels on each factor contributing to the quality of illumination.

(1) *Light Evenly Distributed on Objects to Be Seen.*

Lighting should be provided where seeing is done. It is desirable that this light should be evenly distributed on the surface to be seen and yet that there be enough light on surrounding surfaces so that conditions of extreme contrast will not be encountered. For the more severe visual tasks such as reading, office work, and lathe work, the general illumination should be supplemented by local or detail lighting. It is more important that even distribution of light on working surfaces be attained with detail lighting than with general lighting. This was one of the weakest points observed in present practice. The general use of bare bulbs with reflector shields close to the work produces spots of extremely high intensities on part of the work and practically no addition to the general illumination on other parts of the working surface. As a case in point consider so-called desk and berth light used as chart table light on *Escanaba*. Directly under the fixture an intensity of 100-foot candles was measured, while at the after corner of the chart table the intensity was 1.4-foot candles. Less extreme but similar conditions were observed at the main switch board, at radio operating positions, at gage boards and wherever a reflector shield type fixture was used close to the working plane. If conditions make it necessary that the source be close to the working plane then the area of the luminous source should be large and of low intensity. If a source of high luminous intensity per unit area is to be used then such a source must be placed at a distance from the work or other steps taken to obtain even distribution of light on the working plane. While it will be many years before the flashlight ceases to be essential to the engineer, a glance at the many instruments with self-contained lights on the bridge, or in

the dashboard of an automibile should point the way. In selecting lighting units the question should be asked, "Is this unit to produce general or local illumination?" And then, "Will it give an even distribution of the desired intensity at the points where seeing is to be done?"

(2) *Glare.*

There should be no glare. Glare reduces the ability to see, in extreme cases producing temporary blindness, causes discomfort commonly in the form of headaches and drowsiness, and prolonged exposure to even moderate glare produces injury to the eye which is often unrecognized. Glare is produced by excessive light flux entering the eye, by excessive brightness of light source or its reflection within the field of view, and by excessive contrast of brightness of various portions of field of view. Excessive glare is by far the worst fault of marine installations observed in this study. Until thoroughgoing steps are taken to reduce glare further increases in illumination levels are likely to result in poorer rather than better seeing conditions. Glare can be avoided by the reduction of brightness of light sources that must be in the field of view and the elimination of polished surfaces and surfaces which do not reflect light diffusely, by placing light sources outside the field of view, and by avoiding excessive contrasts.

The low ceiling height makes unavoidable the placement of some fixtures in the field of view.

While polished metal surfaces have long been a tradition of the sea and will probably continue to be so, it is noticed that on modern vessels polished metal surfaces are used much less lavishly than in former years. Where it is desirable to have polished metal or glossy wooden surfaces, glare may be reduced by taking steps to insure that light sources, which may be reflected by these surfaces, are of low surface brightness.

At one time it was the practice to paint interiors with high gloss enamels. With the exception of the aluminum paint used in the machinery spaces the paints now used on Coast Guard vessels are excellent in preventing and minimizing glare by diffuse reflection. Aluminum paint provides only partial diffusion of the light striking its surface, most of the light reflected leaving the surface

in the same general direction. While the image of the light source is spread out, an aluminum painted surface may appear excessively bright at one angle and quite dark at others producing excessive contrasts in the field of view when all surfaces are aluminum painted. In compartments where considerations more vital than illumination make it desirable to paint all surfaces with aluminum paint then all the light sources should be of low surface brightness. Since in these compartments steam and water-tight fixtures are necessary, if aluminum paint is to be retained and glare reduced a rather large number of not over 40-watt fixtures with opal glass enclosing globes should be used.

Excessive contrasts can be avoided by use of semi-direct fixtures. Totally direct fixtures which send all their light to the working plane should be used only to provide local illumination in combination with general illumination produced by semi-direct fixtures. To further reduce contrasts, it is highly desirable that when fixtures to produce local or detail lighting must be placed in the field of view that shields be provided to prevent direct rays from entering the eye and that these shields should be translucent with very low surface brightness rather than completely opaque. Maximum brightness in field of view of direct lighting fixtures equipped with reflectors can be reduced by use of silvered bowl lamps.

The greatest reduction of glare can be accomplished through the reduction of brightness of light sources. Due to the low ceiling which places nearly all sources which are not completely shielded in the line of sight of some individual the maximum brightness of any unshielded light source should not be over 3 candles per square inch and maximum brightness of most unshielded sources should not be over 1 candle per square inch. In order to accomplish this a better diffusing medium for the enclosing globe than etched glass would have to be used. For water-tight installations opal glass could be used. For non-water-tight fixtures either opal glass or urea formaldehyde molded plastic could be used. For installations of fluorescent lamps either water-tight or non-water-tight, methyl methacrylate (Plexiglas) would be a suitable diffusing material. It is true that the introduction of a true diffusing medium for enclosing globes would lower the lumens per watt obtained from the fixture compared with that obtained with the use of etched

glass, but this loss (of order of 15-20 per cent) is hardly great enough to justify the present glare conditions.

An interesting comparison of what may be accomplished in the reduction of brightness by use of better diffusing media is given by the following data from survey of *Escanaba*. The brightness of the brightest spot of a 25-watt inside frosted mazda lamp operated at rated voltage and viewed from an angle of 70 degrees with the axis of the bulb is 17.7 candles per square inch. The brightness of acid etched glass placed normal to the same angle of view of the same bulb was determined as 3.6 candles per square inch by means of a MacBeth Illuminometer. The reduction in brightness was 4.9 to 1. The same test was repeated with a 100-watt bulb having a brightness of 98.0 candles per square inch at the same angle of view and with opal diffusing glass of the type used in commercial semi-direct fixtures placed in the line of sight. The brightness of the opal glass was .955 candles per square inch. The reduction of brightness was 102 to 1.

Because data on identical enclosing globes of different diffusing material is not available, it is not possible to compare the ratio of lumens generated by the lamp to lumens emitted by the enclosing globe. However, this ratio is for most globes nearly proportional to the sum of the reflection and transmission coefficients. This sum for diffusing media aforementioned is given below. Acid etched glass, .97-.98; opal glass (.138 inch thick), .90; urea plastic (.048 inch thick), .90; methacrylate plastic (.25 inch thick), .90. Thicknesses chosen are those which would meet mechanical requirements of non-water-tight diffusing globe.

Thus about twenty times the present reduction in brightness can be obtained with only about 10 per cent loss in efficiency, a loss in efficiency less than that observed due to the practice of operating lamps under their rated voltage.

When the enclosing globe is made of such diffusing material that its brightness is the same over the entire surface then further reductions in brightness (with total lumens output constant) require that the surface area of the enclosing globe be increased. With non-water-tight fixtures this does not present great difficulties. A great variety of well designed industrial and commercial units with brightness values below 1 candle per square inch are

available. Some of these are satisfactory for marine installations and have been installed on Coast Guard vessels. Others with slight modifications to give better resistance to corrosion, vibration and shock would prove suitable. The use of plastic diffusing enclosures of urea formaldehyde for non-water-tight fixtures seems even more desirable in marine installations than ashore, first, because of the weight saving (enclosure of plastic to perform same mechanical and optical tasks may have weight one-third of like article of glass), and second, because of much greater resistance to breakage. Large glass globes to provide low brightness values would increase the risk of breakage, but by selection of fixtures whose globes may be made of plastic, units of low brightness can be obtained and the breakage risk reduced over that now existing.

Where water-tight units must be used the problem of reducing brightness to acceptable limits is much more difficult, but not impossible or impracticable. The first step would be the use of completely diffusing enclosures to obtain uniform surface brightness and eliminate the hot spots produced with etched glass and the barbaric brilliance of clear glass enclosures. At present such enclosures for steam and water-tight units would have to be of opal glass because of the temperature limitations of plastics now available. Plastic diffusing globes could be used on water-tight ceiling fixtures of the shallow dish type and with careful design the possibility exists that the deck type fixture of 25 to 50 watts could be fitted with plastic water-tight globe.

Since the surface area of water-tight units is limited by mechanical requirements it is doubtful that fixtures emitting sufficient lumens from the water-tight enclosing globe to obtain desired illumination levels can at the same time have the desired low surface brightness. The better diffusing materials will be of principal value in reducing reflected glare. To reduce direct glare from water-tight units a logical approach is the use of shields. These shields should not be opaque, but rather made of translucent plastic so designed as to reflect most of the light to the surfaces to be seen, but to transmit enough light to give the outer surfaces of these shields a brightness of about .1 foot candle.

When sources have a brightness of greater than about 3 candles per square inch then objectionable afterimages (images of the source which persist in the eye after the source is removed from the field of view) are found. The greater the maximum brightness of the source, the longer the afterimages persist in the eye and the greater the period of reduced vision or partial blindness.

While a considerable improvement in the designed brightness of light fixtures is highly desirable such improvement may be only temporary if steps are not taken at the same time to permanently affix to the fixture information regarding the size lamp for which a given fixture was designed. The glare conditions observed on the *Escanaba* were only in part due to the original design. The most widely used fixture was a ceiling fixture with 4-inch spherical etched enclosing globe. From the text of the original specifications it appears that a 25-watt lamp was to be used in this fixture, even though the manufacturer classes the fixture as a 50-watt fixture. With the 25-watt lamp in place the fixture had a maximum brightness of 3.6 candles per square inch, a value roughly four times that considered desirable for the low mounting height. In order to increase illumination levels, 50-watt lamps were later placed in these fixtures with a result that the brightness increased to 14.6 candles per square inch or nearly sixteen times the desirable value. In addition to the excessive brightness the heat produced by the higher wattage lamp may be greater than the fixture can dissipate without a rise in temperature such as to bake rubber gaskets and insulation.

A reduction of the number of light sources in the field of view can be made by making fuller use of the shielding effect of the structural members of the ship in combination with fixtures having small vertical drop and surface sources. While it is not desirable to mount fixtures to overhead decking, it is both undesirable and unnecessary that the entire fixture be mounted below the lower flange of the channel beams, for this practice places nearly all fixtures only slightly above eye level of a man standing up. Mounting fixtures so that the area visible to the eye is reduced and the brightest parts shielded from the eye by structural members would contribute materially to reduction of glare.

Fluorescent lamps offer interesting possibilities because of their inherent low brightness which would greatly reduce the amount of diffusion needed. Because of their long tubular shape they seem well adapted to the low overheads encountered on shipboard and suggest adaptations in which the structural members of the ship will aid in the solution of the problem of good illumination.

(3) *Shadows.*

The shadows produced depend upon the amount of diffusion of the light source, the number and placement of light fixtures and their relation to objects in the space lighted and the reflection characteristics of surfaces within the space.

A bare bulb produces shadows that are sharp and dark. The more the light source is diffused the less distinct become the edges of the shadows because light rays are now emitted by a surface and strike the object from different angles. If the number of well diffused sources is increased the number of angles from which light rays strike the object is further increased and the depth of the shadow decreased. If the bounding surfaces are diffuse reflectors, then light diffusely reflected serves to lighten shadows where direct rays or directly reflected rays are obscured. Steps suggested to reduce glare on shipboard would help to reduce shadows.

(4) *Contrast.*

The ratio of maximum to minimum luminosity of objects in the field of view should not exceed 200 to 1 and 100 to 1 is much to be preferred as the upper limit of this ratio. Exceeding this ratio gives rise to glare by contrast. To keep contrast within limits of values given calls for avoiding light sources with high brightness in the field of view, and an even distribution of illumination.

Consider several cases of excessive contrast observed in existing installations. An officer is reading at a wardroom table with an intensity of 8-foot candles on the reading matter having a reflection factor of .8. The luminosity of the reading matter is 6.4 lumens per square foot. He raises his eyes from the reading matter without moving his head and a fixture in the far corner of the wardroom having a brightness of 14.6 candles per square inch

or a luminosity of 6600 lumens per square foot is in view, a contrast ratio of 1030 to 1. Reduction of brightness of fixture to 2 candles per square inch would reduce contrast ratio to 150 to 1.

A radioman is typing a message and turns to set receiver dial to new frequency. Measured luminosity of paper in typewriter was 72 lumens per square foot, luminosity of panel of receiver .15 lumens per square foot. Contrast ratio 470 to 1.

A bulletin board has 25-watt lamp in desk type water-tight fixture with clear glass enclosing globe and no shield mounted at top of board. Luminosity of lamp was 8000 lumens per square foot. Average luminosity of notice on bulletin board was measured as .32 lumen per square foot. Contrast ratio 25,000 to 1.

(5) *Color.*

Color of light should be agreeable, and economical. In marine installations the color of light is not of prime importance as long as the light is agreeable. Color of light emitted by ordinary mazda lamps operated at or slightly above rated voltage is believed to be satisfactory for most purposes. Operation of lamps appreciably below rated voltage not only causes large losses in luminous efficiency of the lamp, but produces a more reddish light to which the eye is less sensitive. The matter of color of light is largely physchological for, excepting tasks involving color matching, it now appears that with equal foot candles of illumination variations in color quality have little or no effect upon the clearness and quickness of seeing.

If for psychological reasons it is desired to have the color quality of light more closely approach daylight than does the plain mazda lamp then steps should be taken to obtain the desired color as economically as possible. The use of the blue daylight mazda lamp is extremely inefficient. The colored glass bulb alone absorbs 44 per cent of the lumens emitted by the filament. If used with an enclosing globe the enclosing globe may absorb a higher percentage of the bluer light than of ordinary mazda light. Measurements of identical fixtures on the *Escanaba,* one with a 100-watt inside frosted mazda lamp and one with a 200-watt blue daylight inside frosted lamp, with both lamps operated at rated voltage showed that within the limits of error of the experiment (4 per

cent) both fixtures were emitting the same number of lumens. If the fixture with the daylight lamp were burning 12 hours per day the value of fuel wasted by this single lamp amounts to $14.90 per year.

If whiter light is desired it is suggested that one economical way to obtain it is by use of overvoltaged lamps. While the color emitted by an overvoltaged lamp, say, a 110-volt lamp operated at 120 volts, is not as near daylight quality as obtained from the daylight bulb, if used with opal glass diffusing globe the difference in the color of light received on the working plane will hardly be great enough to justify the large waste with the daylight lamp. Computations show that if in the above case a 100-watt, 110-volt lamp were operated at 120 volts the cost of increased power consumption over the 100-watt lamp operated at rated voltage would be $2.08 per year and the increase in cost of lamp replacements due to shorter life would be 99 cents, a total increase in cost of $3.07 per year as compared to $14.90 for the daylight bulb. But at the same time the lumens emitted would be 35 per cent greater than with either of the existing installations. If the fixture already provides adequate light then the use of a 75-watt, 110-volt lamp at 120 volts would provide greater economy with a decrease in lumens emitted of only 6 per cent over present installations, an amount considered negligible in its effect on seeing. The saving in power would amount to $3.28 per year over the use of ordinary 100-watt lamp, the added cost of lamp replacements due to decreased life would be 99 cents at present contract prices, resulting in whiter light at a net saving of $2.29 per year per fixture. Thus a very close approach to the same color and quantity of light could be obtained for $17.18 per year less than is now being spent with the use of the daylight mazda lamp.

Another economical approach to obtaining daylight quality is found in the use of daylight fluorescent lamps. The color of light from such lamps is very close to color of a slightly overcast sky, far closer than is obtained with the daylight mazda lamp. The first cost of lamp and auxiliaries is high at present and the efficiencies of these lamps is much lower on D.C. than on A.C. Even so, they will produce light of daylight color when operated on D.C. with about 15 per cent greater efficiency in foot candles produced on

the working plane per watt than mazda lamps operated at rated voltage. The savings in power alone over the 200-watt daylight lamp would pay off the first cost in a year and after that provide daylight quality of light in the same quantity for about $13.00 less per year than the daylight mazda lamp.

(6) *Reliability.*

Lighting should be reliable under all conditions of service and easy to maintain. Present lighting systems on Coast Guard vessels are reliable. Any changes in the lighting of small vessels must at least equal present reliability and if possible improve the dependability of the lighting installation. Two suggested changes made above might be expected to improve reliability. Formulation of specifications requiring water-tight fixtures only where essential accompanied by adoption of standard non-water-tight fixtures designed in accordance with modern standards of illumination engineering and meeting the most rigid marine specifications as regards ability to stand shock and vibration and resistance to corrosion would certainly decrease the number of poorly adapted fixtures with which ships are now supplementing their original lighting equipment. The wider use of plastic globes would decrease breakage and help to make history of the practice of removing enclosing globes before firing of the ship's guns.

(7) *Efficiency.*

System should have as low first cost and operating cost as conditions permit. It is probable that marine fixtures will always be much more expensive than industrial lighting fixtures because of limited quantities and the special requirements of many fixtures. But certainly the manufacturers of marine lighting should be expected to justify this added cost by keeping their designs up-to-date, not only from a mechanical aspect, but from the illumination standpoint as well. Aside from recent designs of the Navy Bureau of Engineering and of the Dayton Manufacturing Co., the leading suppliers of marine lighting have made practically no progress in the optical design of marine fixtures for at least the past 23 years. Comparison of 1939 catalog of one leading supplier of commercial marine lighting fixtures with illustrations of an article on naval illumination by Lieut. C. S. McDowell pub-

lished in 1916 shows the same fixtures, which even at that date were subject to criticism of their suitability. An inspection of the *Walnut,* which was commissioned in 1939 and probably is a fair example of present commercial practice, revealed that the 1916 variety of fixtures had been installed by the builder. This obsolescence is particularly to be noted in the non-water-tight fixtures. Certainly where industrial designs are suited and adaptable to marine use the fact that they were not especially designed for shipboard installation and hence cost less should not stand in the way of their use.

The efficiency with which the marine lighting converts watts to lumens on the working plane is much more important in marine practice than in industrial because of limitations of generator capacity and fuel supply for generators prime mover. Increased efficiency would permit higher levels and better quality of illumination with much smaller increases in generator capacity in the design of new installations and permit improvements in existing installations where the lighting load cannot be materially increased.

In the design of new installations the possibility of using lower voltages for the lighting circuits should be investigated. With A.C. installations this would be relatively simple. On D.C. installations a separate generator or converter unit would be required. Suppose the lighting voltage were dropped from 115 to 30 volts at the socket. A 40-watt mazda lamp designed for and operated at 115 volts gives 11.7 lumens per watt. A 40-watt mazda lamp designed for and operated at 30 volts gives 15.8 lumens per watt, an increase in efficiency of 35 per cent. In addition the more rugged filament of the lower voltage lamp would better withstand shock and vibration and thus have greater average life under service conditions. True, initial wiring costs would increase somewhat and line losses would be greater, but with the comparatively short distribution lines on shipboard it is believed that a clear gain in efficiency of 25 per cent could be expected from the lower voltage. With 60-volt lamps the gain in lamp efficiency would be 18 per cent. In the illumination of trains where vibration, shock, and power limitations are at least similar to those found on small vessels both 30 and 60 volts lighting systems are installed.

In existing installations increased efficiency and decreased cost of operation can be obtained by use of overvoltaged lamps. Many engineer officers at present operate the lamps under their rated voltage to obtain longer life with the belief that this means lower costs. Not only does this practice result in poorer color quality, but the actual cost of lumens on the working plane is increased. Consider following computations of lighting costs made on the *Escanaba*. This vessels was using standard 120-volt mazda lamps with 117 volts at the average socket. 7.15 Kw. of 50-watt lamps and 2.1 Kw. of higher wattage lamps were in use. It is estimated that 75 per cent of the lamps were in operation 4 hours daily, 35 per cent of the lamps were in operation 16 hours daily and about 15 per cent in operation continuously. Daily power consumption at rated wattage with above estimated hours of operation is 87.3 Kwh. Correction for power economy of under voltage give 84.0 Kwh. as daily consumption. At 3.4 cents per Kwh. for fuel, annual cost is $1041. Assume that the average lamp burns 9.5 hours daily (this figure is probably too high, but since same figure has been used in all comparisons it is believed that the *comparisons* are valid) and has normal rated life of 1000 hours. Due to under voltage, average life is increased to 1382 hours. On the above basis 394 lamp replacements per year might be expected. With cost of lamps at 9 cents each and cost of labor to replace lamp estimated at 3 cents per lamp, total cost of lamp replacements, $47.30 per year, making total lighting costs $1088.30 per year. Due to under voltage the lamps are producing only 91.8 per cent of their rated lumens or 392 million lumen-hours per year. The cost of light per million lumen-hours is thus $2.77.

Computation of the most economical voltage rating of lamps for the *Escanaba* on the basis of 58.5 average wattage rating of lamps, .12 lamp replacement cost and .034 per Kwh. power cost shows that the rated voltage of the lamp should be .902 times the socket voltage. With commercially available lamps this means that most efficient operation would be attained with lamps rated for 110-volt operation operated with 122 volts at the socket. Under these conditions of operation the cost per million lumen-hours of light would be $2.51, resulting in an annual net saving of $102 for the same quantity of light.

Overvoltage can be used in two ways. One is to overvoltage present wattage installations and thus obtain higher illumination levels with moderate increase of load and lower cost per lumen-hour. The other is to use reduced wattages of overvoltaged lamps to maintain present illumination levels with decrease in total lighting load.

Consider application of the first method to the *Escanaba,* i.e., maintain present wattages, but use 110 volts lamps with 122 volts at the socket. The first result would be a 50.4 per cent increase over present lumens generated by lighting system, raising illumination levels throughout the vessel. (With existing fixtures which already are too bright this might represent actual decrease in quality of illumination, but with proper fixtures could well be used.) There would be a 17.4 per cent increase in power consumption over rated wattage of lamps, which is a 21.9 per cent increase over present power consumption, raising average total peak load from 76 per cent of generator capacity to 80.6 per cent. Annual lighting power costs on preceding basis of 9.5 hours' use per day would rise to $1270. Average lamp life would decrease to 260 hours, lamp replacements increase to 2100 per year, annual cost of labor and lamps to $252 per pear. The total annual lighting cost would rise to $1522. Thus a 50.4 per cent increase in quantity of light could be obtained for a 40 per cent increase in total lighting costs without overloading existing generators.

Were the *Escanaba's* lamps operated with rated voltage at socket the total lumens generated would increase by 8.2 per cent and the total cost rise but 5.7 per cent.

Use of reduced wattage of overvoltaged lamps to maintain present illumination levels while showing economies of the order of 10 per cent of total cost in theory are economical in practice only in those cases where the lumens per watt efficiency of the next smaller wattage lamp available is very close to the efficiency of the lamp in use. Otherwise the increase in efficiency due to use of overvoltage may be insufficient to offset the inherent lower efficiency of the next smaller wattage. On the *Escanaba* it is possible to obtain same illumination levels with 9 per cent less power by replacing 50-watt and 150-watt lamps with overvoltaged 40 and

100-watt lamps, but the cost of replacements would increase so rapidly that the total lighting cost would increase about 10 per cent. This is because most of the lamps are 50-watt, having an efficiency 12.7 per cent greater than 40-watt lamps at rated voltage. Had the lamps in service been 60-watt then reduction to 50-watt overvoltaged lamps would have been feasible, for the 60-watt lamp is only 4.5 per cent more efficient at rated voltage than the 50-watt lamp. However, when reduction of lighting load is of paramount importance and cost secondary the use of lower wattages of overvoltaged lamps should be considered.

Since the purpose of the lighting system is to provide light, costs should be computed on the basis of the quantity of light furnished, i.e., in dollars per million lumen-hours of light. Only when the cost of power is low and the cost of lamps high will the operation of lamps below rated voltage be justified from the standpoint of cheaper light costs. Tables II, III, and IV present data on cost of light production with sources suitable for Coast Guard use. Power cost of 2.7 cents per Kwh. is average of fuel costs only at average generator load as computed by *Bibb, Escanaba,* and *Cayuga.*

The inconvenience of the larger number of lamp replacements due to use of most economical voltage is not as great in practice as might appear from a consideration solely of the reduced average expected hours life of lamps. A lamp life of 250 hours is twice the life of lamps installed in automobile headlights. Replacement of lamps on shipboard is simpler than in corresponding industrial applications due to much greater accessibility of fixtures. Even for lights in continuous use, where it might be advisable to forego economy of overvoltage, the expected replacement period would be of the order of ten days. With the average fixture the expected replacement period would be between 30 and 60 days. Since globes may be cleaned with little extra labor at time of lamp replacement, a shorter replacement period could be expected to decrease the average loss of light due to dirt accumulation without undue expenditure of labor.

TABLE II.

VARIATION OF LIGHT COST WITH VOLTAGE.

For 50-watt, 115-volt mazda lamps, lamp costs 9 cents, power at 2.7 per Kwh., zero labor cost of replacement.

Socket Voltage	*105*	*110*	*115*	*120*	*125*	*130*
Lumens per watt.....	11.1	12.2	13.2	14.3	15.4	16.5
Watts consumed.....	43.5	46.7	50	53.4	56.8	60.3
Average life, hours.....	3280	1735	1000	570	335	200
Cost of light, dollars per million lumen-hours..	2.48	2.30	2.20	2.10	2.06	2.09

TABLE III.

MOST ECONOMICAL SOCKET VOLTAGE.

For 50-watt lamps of standard rated voltages. Showing effect of total replacement cost (lamp cost + labor) on most economical voltage. Power and lamp costs same as Table II.

Rated Voltage	*110*	*115*	*120*
Labor cents/lamp	*Total Lamp Cost, Cents*	*Most Economical Socket Voltage*	
0	9	121	127	133
3	12	118	124	129
6	15	116	122	127

Computed from equation:

$$V/V_o = (kbW_o/C)^{0.083}$$

Where:

V = Socket voltage
V_o = Rated voltage
b = Power cost, cents/Kwh.
W_o = Rated wattage of lamp
C = Total lamp cost in socket
k = .220 for 40-50-watt lamps
k = .211 for 60-150-watt lamps

TABLE IV.

COST OF LIGHT PRODUCTION.

(Per Million Lumen Hours.)

For sources adaptable for Coast Guard use. Costs for operation neglecting initial cost of fixtures, installation, etc., computed on basis of zero labor cost of lamp replacement, for (110-120-volt) lamps operated at rated voltage, power at 2.7 cents per Kwh., lamp costs under 1939 contract.

Lamp	*Rated Life (Hours)*	*Efficiency (Lumens Per Watt)*	*Lamp Cost (Dollars)*	*Light Cost Per Million Lh.*
General Service Mazda I. F.				(Dollars)
25-Watt	1000	10.6	.09	2.89
50-Watt	1000	13.2	.09	2.20
100-Watt	750	16.3	.09	1.73
150-Watt	750	17.6	.21	1.64
200-Watt	750	18.2	.36	1.62
Vibration Service				
50-Watt	1000	11.0	.15	2.72
Rough Service				
50-Watt	1000	8.9	.22	3.53
Daylight G. S.				
100-Watt	750	9.8	.21	3.04
150-Watt	1000	10.5	.42	2.83
Fluorescent, white on A.C.				
15-Watt	2000	26.2	.8625	1.85
20-Watt	2000	30.4	1.15	1.65
Fluorescent, white on D.C.				
15-Watt	1000 to 2000	14.6	.8625	3.50 to 2.67*
20-Watt	1000 to 2000	20.5	1.15	2.82 to 2.10*

* Accurate data on D.C. life of fluorescent lamps not available.

Computed from formula:

C.p.M. LH = (10/E) (R + P/WL)

Where:

C.p.M. LH = Cost per million lumen hours in dollars
E = Lumens per watt
P = Lamp cost in cents
W = Total watts consumed
L = Average life in thousands of hours
R = Power cost in cents per kilowatt hour

Another efficient method of obtaining light on shipboard lies in the use of fluorescent lamps. They offer high efficiencies in low wattage units. A 20-watt white fluorescent lamp with auxiliaries consumes a total of 37 watts when operated on D.C., but still is able to show a net efficiency of 20.5 lumens per watt, an efficiency which is equalled in tungsten lamps only in wattages of 300 and above which are unsuited for interior lighting of small vessels. The same fluorescent lamp operated on A.C. shows a net efficiency of 30.4 lumens per watt. Very real reductions in the lighting load for equal illumination levels are offered by these lamps. With a total power consumption of 37 watts on D.C., a 20-watt white fluorescent lamp will give 15 per cent more lumens than a 50-watt tungsten lamp at rated voltage. This value corresponds to a 30 per cent reduction in lighting load for the white lamp to produce equal illumination levels as compared with 50-watt tungsten lamp. On A.C. the reductions in power consumption are even greater, amounting to a 56 per cent reduction if white fluorescent lamp is used.

Even with present high cost of fluorescent lamps, the cost of light production per million lumen-hours is between $2.10 and $2.82 for D.C. operation and $1.65 for A.C. operation of 20-watt white lamps.

(8) *Appearance.*

While lighting on Coast Guard vessels is utilitarian rather than decorative it is desirable that the lighting fixtures should harmonize with the surroundings and should contribute to the appearance of the compartment whether lighted or dark. Design should facilitate cleaning and lamp replacement. Materials should be unaffected by salt air so that no deterioration in appearance shows up after fixture has been in service for some time.

THE BEHAVIOR OF NICKEL COPPER ALLOYS IN SEA WATER.

By F. L. LaQue.*

The author presents a most complete work relative to corrosion of nickel-copper and copper-nickel alloys. The subject is handled in such a manner as to avoid controversial matters and proper emphasis has been given to the several factors which must be considered in selecting a particular alloy for a definite purpose.

The article contains something new in describing the resistance of certain alloys to edge corrosion and also the rather definite conclusions relative to the copper content of alloys necessary to resist fouling.

The object of this paper is to provide a general view of the whole range of nickel copper alloys with respect to their behavior in sea water. No attempt will be made to give a detailed description of the corrosion resisting characteristics of any particular alloys, although attention naturally will be focussed on those compositions which are of greatest commercial importance.

General Resistance to Salt Water Corrosion.

Data on the resistance of nickel copper alloys to corrosion by sea water, as measured by weight loss determinations, provide a broad picture of the effect of nickel content on overall resistance to sea water attack. The principal trend shown by such data is for overall corrosion to decrease as the nickel content of the alloy is raised. This trend may be shown readily by means of short time laboratory tests in sodium chloride solutions. Some typical results obtained in this way are given in Table 1.

A similar effect of nickel content is also observed in long time tests made by exposing specimens to natural sea water. One of

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the several tests of this sort which have been carried out by the author and his associates will be described in some detail, since the data derived illustrate the point under discussion particularly well.

TABLE 1.

RESULTS OF LABORATORY TESTS ON A NICKEL COPPER SERIES IN AERATED 3 PER CENT SODIUM CHLORIDE.

Temperature: 86 degrees F.
Agitation: Specimens moved at a velocity of 15 feet per minute.
Duration of Tests: 20 hours.

Approximate Composition of Alloy	*Rate of Corrosion in mg./sq. dm./day*
100% Copper	76
70% Copper, 30% Nickel	28
55% Copper, 45% Nickel	28
30% Copper, 70% Nickel	2
100% Nickel	2

The specimens used in this test were in the form of panels measuring 8 inches by 24 inches by ⅛ inch thick. They were mounted on racks so that they were insulated from each other and from the racks and were immersed to about two-thirds their depth in sea water which flowed through a channel at the plant of the Ethyl Dow Chemical Company, Wilmington, North Carolina. The racks were suspended from a bridge over the channel and were placed so that the water impinged on the upstream edge of each specimen. The water velocity varied from about 3 feet per second at the surface to about 1.5 feet per second at the depth of the bottoms of the specimens. The water flow was turbulent and the level tended to fluctuate so that there was no constant or well defined water line. The results of this test, referring to exposure of specimens for a total period of 497 days, are shown graphically in Figure 1.

Nickel copper alloys were included by W. H. Bassett and C. H. Davis [1] in one of the earliest and most extensive investigations of the behavior of copper alloys in salt water.

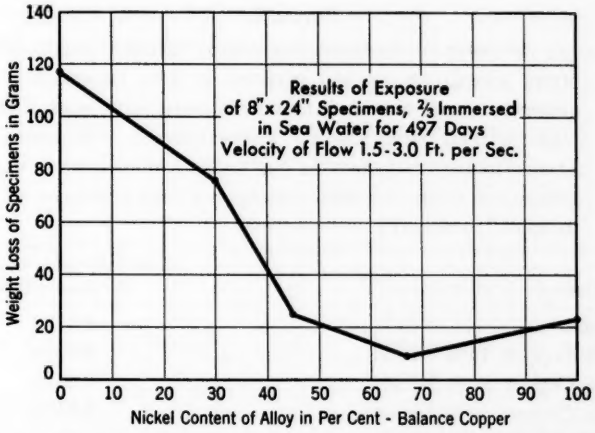

FIGURE 1.—EFFECT OF NICKEL CONTENT ON THE WEIGHT LOSS OF NICKEL COPPER ALLOYS IN FLOWING SEA WATER.

These tests were aimed primarily at the selection of tubes for condensers in which salt water would be used as a cooling medium. The main body of specimens was, therefore, in the form of tubes, but, in addition, there were included a number of sheet metal specimens of the same alloys which were used in making weight loss determinations. Some of the results referring to exposure to salt water from New York harbor for over eight years have been abstracted in Table 2. Data on the tubular specimens were confined to records of the time to failure of vulnerable materials, observations on the general appearance of the tubes after exposure, and estimates of the maximum depth of pitting. All of the nickel copper alloy tubes survived the test and were reported to be in good condition. It should be noted that this test did not include sufficiently drastic conditions of water velocity and air impingement to enable the nickel copper alloys to demonstrate their greatest advantage over the other alloys with which they were compared.

Some data on the effect of a small percentage of nickel (1.75 per cent) and a comparison between copper and nickel were provided by the results of tests reported by J. N. Friend.[2] The specimens used in these tests were round bars, 1⅛-inch diameter by 23 inches long. These were mounted in wooden racks located at half tide level in the Bristol Channel for four years. The results are shown in Table 3.

TABLE. 2.

RESULTS OF TESTS ON COPPER AND COPPER NICKEL ALLOY SPECIMENS ANNEALED AT 450 DEGREES C. AND IMMERSED IN A RESERVOIR FROM WHICH SALT WATER FROM NEW YORK HARBOR WAS PUMPED THROUGH AN EXPERIMENTAL CONDENSER AT ATMOSPHERIC TEMPERATURE FOR EIGHT AND ONE-HALF YEARS. SPECIMENS WERE CLEANED AND WATER WAS RENEWED AT SIX MONTHS' INTERVALS.

Material	*Loss in Weight in Grams Per Square Inch*
Copper	0.0122
85% Copper, 15% Nickel	0.0112
80% Copper, 20% Nickel	0.0110
75% Copper, 25% Nickel	0.0104

TABLE 3.

RESULTS OF TESTS ON BARS EXPOSED AT HALF TIDE LEVEL IN BRISTOL CHANNEL FOR FOUR YEARS.

Material	*Loss in Weight After Cleaning In Grams*	*Per Cent Loss in Tensile Strength as Result of Exposure*
Copper	128.1	4.37
Nickel Copper (1.75% Ni)	106.3	1.49
Nickel	14.8	.....

Similar tests on the same size of bar specimens were carried out at Southampton Docks, England.[2] In this case, the duration of the test was three years. The specimen frames were fixed under a jetty at approximately half tide level.

At this test location the specimens became covered with thick coatings of oily mud. In addition, all but the copper and high copper alloy specimens acquired growths of marine organisms which stimulated local corrosion, especially in the case of some alloy steels which were included in the test. The results on the nickel copper alloys with some notes on effects of marine organisms are given in Table 4. A comparison of the data for copper in Table 3 with that in Table 4 shows that the oily coatings which formed at

Southampton tended to stifle corrosive attack. Nevertheless, the data confirmed the trend of the effect of nickel content.

TABLE 4.

RESULTS OF TESTS ON BARS EXPOSED AT HALF TIDE LEVEL AT SOUTHAMPTON DOCKS FOR THREE YEARS.

Material	*Loss in Weight After Cleaning in Grams*	*Remarks*
Copper	3.50	Uniform corrosion, no shell fauna
98% Copper, 2% Nickel	3.9	Uniform corrosion, no shell fauna
90% Copper, 10% Nickel	2.35	No evidence of attack connected with shell fauna
80% Copper, 20% Nickel	1.25	Uniform corrosion, no shell fauna
55% Copper, 45% Nickel	0.20	Traces of attack under shell fauna
28% Copper, 70% Nickel	0.00	Traces of attack under shell fauna
Nickel	0.25	Slight attack under shell fauna

TABLE 5.

RESULTS OF TESTS ON SHEET METAL TENSILE SPECIMENS IMMERSED IN SALT HARBOR WATER AT BRIDGEPORT, CONN., FOR 243 DAYS.

Material	*Corrosion Rate in mg./sq.dm./day*	*Loss of Mechanical Properties in Per Cent*	
		Strength	*Elongation*
Phosphorized Copper	14.7	14.4	11.0
83% Copper, 17% Nickel	8.8	10.4	7.7
75% Copper, 20% Nickel, 5% Zinc	8.6	8.9	16.3
70% Copper, 29% Nickel, 1% Tin	5.5	2.5	6.2
30% Copper, 70% Nickel	6.0	5.0	8.0
Nickel	5.0	2.5	8.3

Salt water corrosion tests which included several nickel copper alloys were conducted by Sub-Committee VII of Committee B-3 of the American Society for Testing Materials. The data shown in Table 5 were abstracted from the results of these tests.[3]

Behavior in Marine Atmospheres.

The conditions of exposure of the specimens used in obtaining the data given in Figure 1 and in Tables 3 and 4 included the corrosive effects of marine atmospheres in addition to sea water itself. Some data referring only to atmospheric exposure have been provided by the results of the long time tests carried out by Sub-Committee VI of Committee B-3 of the American Society for Testing Materials.[4]

Figures obtained from tests lasting six years at Sandy Hook, New Jersey, and LaJolla, California, are given in Table 6. With most of the metals and alloys included in this testing program, corrosion was considerably more severe at LaJolla than at Sandy Hook; however, it will be noted that this was not the case with the nickel copper alloys which performed exceptionally well at the LaJolla test site.

The severity of the corrosiveness of the atmosphere towards most materials at the LaJolla location was attributed to the fact that the test racks were located very close to the beach where breaking waves threw up a fine mist of salt spray and to the numerous heavy fogs and dense mists which drifted in from the ocean and condensed on exposed surfaces and thereby kept corrosion product films more or less wet most of the time. It is probable that the data obtained from tests at the LaJolla location are more indicative of what may be expected from metals used aboard ships where similar salt spray mists are commonly encountered.

It should be noted that corrosion product scales or films were not removed from the specimens before they were re-weighed in connection with the determinations of changes in weight. Consequently, the changes in weight figures in Table 6 are less useful than the figures referring to changes in mechanical properties in evaluating the performance of the alloys in marine atmospheres. Some supplementary data referring to specimens which were

TABLE 6.

RESULTS OF EXPOSURE OF SPECIMENS TO MARINE

Material	Average Change in Weight of 9-Inch × 12-Inch Specimens. Corrosion Products Not Removed—Grams						Percentage Change in After Six	
	At Sandy Hook			At LaJolla			Strength	P
	After 1 Yr.	After 3 Yrs.	After 6 Yrs.	After 1 Yr.	After 3 Yrs.	After 6 Yrs.	At Sandy Hook	At LaJolla
Copper (Tough Pitch)	+0.54	+0.50	+0.20	+1.51	+1.84	+2.29	—2.4	—5.7
75% Cu, 20% Ni, 5% Zn	+0.10	—1.11	—3.38	+0.48	+0.33	—0.04	—2.3	—0.6*
70% Cu, 29% Ni, 1% Sn	+0.10	—0.80	—2.90	+0.32	+0.16	—0.25	—3.6*	—2.6*
32% Cu, 65% Ni	—0.43	—1.80	—4.18	+0.17	—0.24	—0.74	—1.3	+0.2*
Nickel	—0.74	—2.38	—5.12	+0.09	—0.19	—0.55	—1.4	—0.1*

* Values less than maximum percentage difference due to chance.

LE 6.

O MARINE ATMOSPHERES FOR SIX YEARS.

e Change in Tensile Properties After Six Years				
rength	*Percentage Elongation*			
At LaJolla	*At Sandy Hook*	*At LaJolla*	*Appearance of Specimens After Six Years*	
			At Sandy Hook	*At LaJolla*
—5.7	—1.6*	—1.8*	Olive green over red brown, adherent fairly smooth scale with spots of patina green	Red brown film with overlying blue-green friable scale, heaviest at edges
—0.6*	—1.6*	—1.3*	Irregular gray-green friable scale over brown adherent film	Light green, thin, smooth scale over thin adherent film
—2.6*	+7.6*	+7.6*	Green-gray scale with brown spots exposed near edges	Light green, smooth, thin scale over tan adherent film
+0.2*	+1.1*	—0.8*	Yellowish powdery film with metallic lustre	General tarnish with spots of light green scale
—0.1*	+0.5*	—1.4*	Smooth slate colored film	Slight speckling of powdery scale, underlying tarnish

cleaned thoroughly prior to weight loss determinations are given in Table 7. These latter data indicate that in marine atmospheres the corrodibility of the nickel copper alloys decreases as the nickel content is raised.

TABLE 7.

RESULTS OF EXPOSURE OF SPECIMENS ABOVE HIGH TIDE LEVEL.

	Corrosion Rates in mg./sq.dm./day	
Material	*274 Days at Eastport, Me.*	*180 Days Near Wilmington, N. C.*
Copper	0.3	2.4
80% Copper, 20% Nickel	0.26	0.94
75% Copper, 20% Nickel, 5% Zinc	0.17	0.62
70% Copper, 30% Nickel	0.19	0.71
55% Copper, 45% Nickel	0.15	0.59
30% Copper, 67% Nickel	0.08	0.33
Nickel	0.04	0.22

It is also evident from the remarks on appearance after exposure in Table 6 that the extent of scaling or film formation and discoloration of the alloys in marine atmospheres decreases as the nickel content of the alloys increases.

The data in Table 6 referring to changes in mechanical properties demonstrates that the nickel copper alloys are not subject to serious strength weakening types of attack when exposed to marine atmospheres. By way of comparison, it may be noted that a vulnerable alloy suffered a 32 per cent loss in strength and an 87 per cent loss in ductility (as measured by percentage elongation) during the six years' exposure at LaJolla, whereas none of the nickel copper alloys showed changes in mechanical properties beyond the calculated limits of accuracy of the determinations.

SPECIAL PROPERTIES.

Most of the weight loss data which have been cited refer to relatively quiet exposure to sea water and are useful principally to indicate the broad trends of effects of composition on the corrodibility of alloys within the nickel copper system. These data

are not sufficient to provide a generally usable basis for choosing the best alloy for any particular service except in those instances where the conditions of exposure are expected to correspond to those which obtained during the tests.

In order to use the available alloys to best advantage, it is necessary to know something about such particular corrosion resisting characteristics as:

1. The ability of the alloy to withstand the erosive effects frequently associated with exposure to sea water flowing at high velocity.

2. The tendency of the alloy to suppress the adherence and growth of marine organisms (barnacles), i.e., the anti-fouling characteristics of the alloy.

3. The distribution of corrosion, that is, whether it tends to be uniform or localized, which conditions favor local attack, and the probable intensity of such attack when it occurs.

4. The galvanic relationships of the alloy to other metals and alloys with which it may, or must, be used.

In many instances a consideration of the several properties just mentioned will leave some latitude in the choice of composition. In such cases, such important incidental factors as physical and mechanical properties, availability in the required forms, cost and practical experience will determine the choice of material. In fact, these incidental considerations are frequently of controlling importance.

Behavior in Sea Water at High Velocity.

The commercial development of nickel copper alloys containing less than 50 per cent nickel, excluding the nickel copper zinc alloys or nickel silvers, was based principally on their ability to withstand the erosive effects encountered in marine condensers in which the velocity of the cooling water was high.

When copper alloys, including nickel copper alloys, are exposed to the corrosive action of salt water their natural tendency is to acquire coatings or films of insoluble corrosion products which are able to stifle corrosive attack. The response of the alloys to the effects of velocity is, therefore, influenced to a considerable extent

by the nature of the films which are formed, particularly with respect to the facility with which they are formed originally, their ability to withstand destruction by erosion, and the speed at which they are re-formed when destroyed by unusually severe action.

The rationalization of the effects of velocity and the factors which complicate it has been particularly useful in the study of deterioration of condenser tubes and in the development of better condenser tube alloys.

Tests by Bengough and May [5, 6] on copper and copper alloy specimens exposed to the action of a jet of sea water established that the destructive effect on the corrosion protective films was not a simple function of the velocity of the jet but was influenced to a most important extent by the presence and size of air bubbles entangled in the water. The primary action of these air bubbles in destroying films and thereby promoting progressive attack was established as being mechanical rather than chemical.

Sir Charles Parsons demonstrated that similar effects were likely to be associated with cavitation phenomena.[7]

While the nature of these effects makes it difficult to provide quantitative illustrations of the effect of nickel content on resistance to impingement attack, practical experience with condenser tubes and laboratory tests using jets and experimental condensers have shown that nickel copper alloys of proper nickel content are especially resistant to the "impingement" effects associated with high velocities.

In the tests by which the data plotted in Figure 1 were obtained, and which have been described in some detail, the upstream edges of the specimens were subjected to a form of velocity erosion or impingement. Observations after exposure for 497 days are described in Table 8.

Similar observations of the downstream edges of these specimens showed no similar evidences of erosion of the vulnerable materials, thereby demonstrating that the effect was a form of impingement attack rather than a simple edge effect. In the case of pure nickel which showed pitting, but no erosion of the upstream edge, similar pitting was observed on the downstream edge as well, and, therefore, was probably not connected with erosive effects.

TABLE 8.

THE EFFECT OF NICKEL CONTENT ON THE RESISTANCE OF NICKEL COPPER ALLOYS TO EROSION BY SEA WATER AS INDICATED BY APPEARANCE OF UPSTREAM EDGES OF SPECIMENS PARTIALLY IMMERSED IN FLOWING SEA WATER FOR 497 DAYS.

Material	*Condition of Upstream Edges*
Copper	Slightly eroded
Silicon Bronze (96% Cu)	Severely eroded
Nickel Silver (18% Ni)	Moderately eroded
Copper Nickel (70% Cu, 30% Ni)	Rounded slightly
Copper Nickel (55% Cu, 45% Ni)	Sharp—unattacked
Monel (30% Cu, 67% Ni)	Sharp—unattacked
Nickel	Sharp, but pitted

M. S. Noyes,[8] in a paper which appeared in this JOURNAL, cited some data bearing on the subject under discussion, obtained from tests carried out at the U. S. Naval Engineering Experiment Station. For convenient reference, these data will be reviewed here.

In one series of tests, specimens in the form of 2-inch O.D. tubing were rotated at high velocity while partially immersed vertically in brackish water. The data in Table 9 refer to the conditions of the copper nickel alloy specimens after this test.

This investigation also included exposure of specimens to the action of salt water jets. The relative behavior of the copper nickel alloys was shown most clearly by tests in which the solution used contained 20,000 parts per million of chlorine in the form of chlorides. At a jet velocity of 14 feet per second the 70 per cent copper, 30 per cent nickel alloy showed a definite superiority over the 85 per cent copper, 15 per cent nickel composition. Similarly, with a jet velocity of 25 feet per second, the 80 per cent copper, 20 per cent nickel alloy was attacked to a considerable extent after four days, whereas Monel (65 per cent nickel) specimens revealed no evidence of attack.

TABLE 9.

RESULTS OF TESTS ON TUBULAR SPECIMENS ROTATED WHILE PARTIALLY IMMERSED VERTICALLY IN BRACKISH WATER.

Material	*Duration of Test*	*Velocity of Rotation*	*Condition After Test*
Copper Nickel (85% Cu, 15% Ni).....	121 Days	10 feet/second	Surface roughened
Copper Nickel (75% Cu, 20% Ni, 5% Zn).....	121 Days	10 feet/second	Surface roughened
Copper Nickel (85% Cu, 15% Ni).....	65 Days	20 feet/second	Surface roughened
Copper Nickel (75% Cu, 20% Ni, 5% Zn).....	65 Days	20 feet/second	Surface roughened
Copper Nickel (70% Cu, 30% Ni).....	41 Days	20 feet/second	Surface smooth—least attacked of materials tested
Monel (30% Cu, 67% Ni).....	41 Days	20 feet/second	Surface smooth

These tests were directed towards the choice of a material for salt water piping on naval vessels and the following conclusions were quoted from the test report:

"Results of tests up to the present time indicate that Monel metal is comparable with the 70:30 copper nickel alloy and should give good service under conditions of salt water corrosion when fittings of like composition are used.

"In general, the copper nickel alloys have shown greater resistance to the several types of corrosion attack than copper, red brass, silicon manganese bronze or Admiralty metal. The 75:20:5 copper-nickel-zinc alloy appears to offer no advantage over the 70:30 copper nickel composition. However, the former alloy has shown up fully as well as the 80:20 and 85:15 copper nickel alloys."

A unique and useful method of studying the performance of alloys subjected to the corrosive action of salt water at high velocities has been developed in the laboratories of the American Brass Company and was described by J. R. Freeman and A. W. Tracy.[9] This method makes use of specimens in the form of discs 6 inches in diameter by 0.050 inch thick. These discs are insulated from

each other and mounted on a shaft so that they are immersed in a testing solution to a depth of approximately 2½ inches. As the shaft is rotated, the discs spin through the solution which becomes aerated through the motion of the discs. This motion also tends to cause the temperature of the solution to rise to from 22 to 24 degrees F. above room temperature. The peripheral speed of the discs is, of course, determined by the speed of rotation of the shaft. In their tests, these investigators used a peripheral speed of 26 feet per second which decreased uniformly along the radii towards the center of each disc.

Nickel copper alloys were included in a series of specimens which were rotated for seven months at a peripheral speed of 26 feet per second in a 2½ per cent solution of Turk's Island sea salt.

In this test, a specimen of electrolytic copper was corroded down to a diameter of 4⅞ inches which was equivalent to a peripheral velocity of 21 feet per second. It was also noted that the protection afforded by films formed below this velocity was incomplete, since numerous pits and bare spots developed.

A specimen of a nickel copper alloy containing 8 per cent nickel was able to maintain a protective film at velocities up to 23 feet per second, while the alloy containing 75 per cent copper, 20 per cent nickel and 5 per cent zinc maintained a protective film right up to the extreme edge which, as previously mentioned, travelled at a speed of 26 feet per second.

Laboratory tests by other investigators using experimental condensers and jets with velocities up to 15 feet per second on a series of copper nickel alloys ranging in nickel content from 20 per cent to 70 per cent showed that while the 20 per cent alloy suffered a slight amount of impingement attack, the alloys of higher nickel content were free from the effect.

A large scale practical trial of tubes which threw considerable light on the effect of nickel content on resistance to impingement attack in marine condensers was described by J. Johnson [11] from whose paper the following is quoted:

"A study of the claims of steam plant, present or prospective, must necessarily be preceded by full consideration of the condenser problem. In this connection, the history of the steamers *Melita's* and *Minnedosa's* main condensers are of special interest

as examples of acute tube deterioration. They are of the 'Uniflux' type, with relatively high velocity cooling water. The Admiralty mixture brass tube (70 Cu, 29 Zn, 1 Sn) had an average life of one year with or without an electrolytic process, but a few months of service produced failures sufficiently numerous to be embarrassing under service conditions. In February, 1925, the *Minnedosa's* condensers were re-tubed with cupro-nickel tubes of 80 Cu, 20 Ni composition. At the same time, the *Melita's* condensers were re-tubed with alternate rows of 90 Cu, 10 Ni and 85 Cu and 15 Ni. There were no failures in either vessel during the ensuing year, and on examination of a large batch from each condenser no sign of deterioration was found in the 80/20 tubes, and only the slightest suspicion of corrosion in the 85/15 tubes. The 90/10 tubes, however, exhibited the same appearance as the earlier brass tubes, practically the whole of the interior surfaces being lightly pitted. Although no perforation had occurred, it was clear that a comparatively short life only might be expected of these tubes. It was concluded, therefore, that anything less than 20 per cent of nickel was not sufficient, that 20 per cent might be adequate, but that an increase in the nickel content would probably be beneficial. The tubes in the *Melita's* condensers were replaced by 80/20, and a proportion of 70/30 (Cu-Ni) tubes introduced, the latter being commercially available at this juncture.

"During the second year there were no failures in the *Minnedosa's* condensers, and in January, 1927, after two years' service, a batch of tubes was withdrawn from both port and starboard condensers and subjected to careful scrutiny, when no indication of general deterioration was observed. During the third year there were four failures, and at the annual overhaul in December, 1927, 100 tubes were withdrawn from each condenser. These were very carefully examined, and while their general condition was good, there were signs of slight corrosion in irregular paths, principally towards the ends, the depth varying from 0.004 inch to 0.010 inch (original thickness 18 w.g. = 0.048 inch). During the fourth year there were two failures and at the overhaul in December, 1928, batches of tubes were drawn and subjected to microscopic examination.

"The examination showed that in all there have been six tube failures in four years and there is reason to believe that these had their origin in manufacturing defects. The most recent examination would seem to indicate that the life of these tubes will not be less than six years. There are fair grounds for supposing that the life of 70 Cu, 30 Ni tubes will be much longer in condensers designed on modern lines. In view of the severity of the case, the first two years' experience with the 80/20 tubes was thought to warrant the belief that a partial solution of the condenser problem was within reach. On the strength of this conviction, together with growing evidence in other quarters, it was decided that the question of adopting high pressure water-tube boilers was ripe for examination."

Mr. Johnson's company, Canadian Pacific Steamships, Ltd., was one of the first to use copper nickel alloy tubes and has continued to use them.

While there is some experimental and practical evidence to indicate that resistance to impingement attack increases with nickel content above 30 per cent nickel, practical experience has demonstrated that the level of resistance provided by the 30 per cent nickel alloy takes care of the severest velocity conditions normally encountered in marine condensers. In this connection, it may be noted that 70:30 copper nickel alloy tubes are being used successfully and to a considerable extent in condensers operating with a water velocity of 15 feet per second.[10] Furthermore, 70:30 copper nickel tubes were specified for use in some condensers recently designed to operate with a cooling water velocity of 20 feet per second.

The advantage of alloys of higher nickel content may be of practical value in cases where erosive or impingement effects are known to be abnormally severe.

Limitations of space will not permit a listing of even a few of the merchant vessels, in addition to the large number of naval vessels, in which 70:30 copper nickel alloy tubes have been installed, but the citing of the names of such ships as the *America,* the *Manhattan,* the *Queen Mary,* the *Queen Elizabeth,* the *Empress of Britain,* the *Niew Amsterdam,* the *Europa,* the *Champlain,* the *Rex* and the *Shanghai Maru* will serve to illustrate the world-

wide recognition that has been given this copper nickel alloy as the preferred material for marine condenser tubes.

Anti-Fouling Characteristics.

It is a well known fact that copper and high copper alloys tend to remain clean, that is, free from barnacles and other adhering marine organisms when immersed in sea water. Such anti-fouling characteristics seem quite definitely to be associated with a toxic effect of copper salts (products of corrosion) rather than with any peculiar property of a copper or high copper alloy surface as such. That this is true was demonstrated by some tests carried out by W. J. Copenhagen.[12] The specimens included one made up by attaching pieces of zinc and brass (80 per cent Cu, 20 per cent Zn) to a piece of mild steel, and another which consisted entirely of the brass. These were hung overboard in sea water at Simonstown, South Africa, and when examined after six months it was found that whereas the brass specimen exposed by itself had remained clean, all parts of the composite specimen, including the brass, were covered with a heavy growth of hard shell. Evidently the galvanic action of the zinc and iron on the brass suppressed the normal corrosion of the brass so that the concentration of copper corrosion products formed was insufficient to be toxic to the barnacles. Similar observations have been made by the author in connection with galvanic couples of copper and iron immersed in sea water. There is also some evidence to indicate that the formation of calcareous coatings on a copper alloy surface may suppress corrosion to an extent which will enable fouling to proceed on top of such coatings.

These examples have been cited to draw attention to the fact that the fouling characteristics of an alloy are not a constant property, but will vary with the conditions of exposure, and probably with the nature of the organisms which tend to grow. In the case of the nickel copper alloy system, the alloys will be anti-fouling under those circumstances where the relationship between the rate of attack by sea water and the copper content of the alloy is such as to result in a sufficiently high copper concentration in the corrosion products to prove toxic to the marine organisms.

Some data bearing on this point were obtained from a test in which a series of nickel copper alloy specimens of varying copper content were immersed in Barnegat Bay for 140 days during the barnacle growing season. The appearance of these specimens after they were removed from the water is shown in Figure 2. It would appear from this photograph that all the alloys containing more than 50 per cent copper were anti-fouling. However, close inspection of the specimen containing 55 per cent copper showed a small amount of plant like marine growth, as well as a few "tubes" such as Vermetus and Serpula. Consequently, it was concluded that at this test location a copper content of at least 60 per cent was required in order to prevent fouling.

A similar series of specimens was exposed in New York harbor water in the Kill van Kull. At this test location the rates of corrosion were generally somewhat higher than at Barnegat Bay with the result that a lower copper content sufficed to make the alloys anti-fouling. In the Kill van Kull test, all alloys containing 50 per cent copper or more did not foul.

Estimations of the rate of solution of copper from the different specimens indicated that at Barnegat Bay an average rate of solution of 7 milligrams of copper per square decimeter per day was sufficient to suppress the growth of marine organisms. The figure for Kill van Kull was about 10 milligrams of copper per square decimeter per day. In the case of an alloy containing 70 per cent copper and 30 per cent nickel the indicated rates of copper solution would be equivalent to loss of metal at rates of from 0.0015 to 0.0025 inch per year.

These observations on the relationship between copper content and fouling characteristics of nickel copper alloys have been confirmed by other tests of a similar nature and by practical experience with the alloys in service.

As a general rule, it may be said that where the copper content of a nickel copper alloy exceeds 60 per cent, fouling is not likely to occur. Where the copper content is less than 50 per cent, fouling is likely to occur. Where the copper content is between 50 and 60 per cent, the extent of fouling will vary, depending on the incidental conditions of exposure as they affect rates of corrosion.

Anti-fouling characteristics of the alloys containing around 30 per cent nickel are not associated with destructive rates of corrosion.

Distribution of Corrosion.

Many practical corrosion problems are concerned not so much with overall rates of corrosion, but rather with the non-uniformity of the corrosive attack. Localized corrosion may take one or more of several forms, such as pitting, water line attack, and such peculiar phenomena as plug type dezincification which is sometimes encountered in copper zinc alloys.

Pitting.

The ultimate causes of pitting are obscure, but the mechanism by which pits are propagated frequently involves the action of concentration cells of either the metal ion or oxygen type, or both. Limitations of space prevent a detailed exposition of the nature of these cells which have been described in standard works.[13, 14] It will suffice to state that for such cells to start and to continue to function, it is necessary that there be a difference in the concentration of dissolved oxygen or metal ions in the solution in contact with definitely separated points on the metal surface. Anything, such as differential velocities, stagnation of liquids in cracks or crevices, or under adherent porous solids, that will tend to maintain such concentration differences will favor the action of concentration cells.

Metals and alloys differ with respect to the intensity of their response to each type of concentration cell. In the case of nickel copper alloys, it has been found that with nickel and high nickel alloys the oxygen concentration cells are most important, the action probably being complicated by potential differences between active and passive areas on the high nickel alloy surfaces. With copper and high copper alloys the metal ion cells are likely to be most active.

The direction of the current flow in a metal ion concentration cell is such as to cause accelerated corrosion of that part of the metal surface which is in contact with the solution having the

lowest metal ion concentration. In the case of an oxygen concentration cell the accelerated corrosion occurs where the oxygen concentration is least.

The effect of these directions on the localization of concentration cell corrosion may be illustrated by assuming that the setting up of a concentration cell has been due to the presence of an adherent porous deposit on the metal surface. The results of normal corrosion tend to cause an accumulation of metal ions and a decrease in the concentration of dissolved oxygen beneath the deposit. The effect of the increased metal ion concentration under the deposit is to cause accelerated corrosion of the metal around the outside edge of the deposit where a solution of lower metal ion concentration is first encountered. On the other hand, the decrease in oxygen concentration beneath the deposit sets up a cell tending to cause accelerated corrosion of the metal under the deposit.

Just where corrosion will occur in any case will be determined by the relative powers of the opposing metal ion and oxygen cells. Since oxygen cells are likely to be most important with nickel and high nickel alloys, any accelerated corrosion that occurs will be located beneath the deposit. With copper and high copper alloys where metal ion cells are likely to control, corrosion will occur around the edge of the deposit.

Similar effects may be observed at breaks in a corrosion product scale on high copper alloys where the metal exposed at the breaks is in contact with a solution containing only a small concentration of copper ions as compared with the surrounding metal which lies under the scale and is in contact with copper rich corrosion products. These circumstances bring about accelerated attack at breaks in the corrosion product scale.

Since metal ion cells and oxygen cells oppose each other, and since high nickel and high copper alloys differ in the extent of their response to each type of cell, it follows that with an appropriate composition of alloy the opposing corrosive forces should tend to balance each other and thereby reduce, or eliminate, localized corrosion of the concentration cell type. Some such action may account for the general uniformity of corrosion of several of the alloys in the nickel copper system. In fact, this may be the

principal basis for the observed superiority of the 70:30 copper nickel alloy condenser tubes over other condenser tube materials under conditions where pitting is likely to occur. In this connection, May[10] has stated: "At present the cupro-nickel must be looked upon as the most reliable as regards pitting, and it achieves this distinction not by complete resistance to pitting, but by the fact that any pits which start tend to widen rather than deepen so that they develop into small areas of comparatively shallow attack which easily becomes stifled by the formation of a new protection film."

Barnacles and other marine growths which may become attached to metal surfaces may serve to initiate concentration cells. Consequently, those alloys which are non-fouling benefit by this freedom from a common cause of local attack. In the case of the higher nickel alloys on which marine organisms may grow, some local attack may occur under the attached organisms. The attack is likely to be greatest with pure nickel, and to decrease as the nickel content is decreased. This effect is illustrated by the data given in Table 10 referring to the depths of local attack on the submerged portions of the partially immersed specimens, the weight losses of which were shown by Figure 1.

TABLE 10.

THE EFFECT OF NICKEL CONTENT ON THE SUSCEPTIBILITY OF NICKEL COPPER ALLOYS TO LOCAL ATTACK. SPECIMENS PARTIALLY IMMERSED IN FLOWING SEA WATER FOR 817 DAYS.

	Depth of Local Attack on Immersed Portion in Inches	
Material	*Maximum*	*Average of Ten Measurements*
Copper	None	None
Nickel Silver (18% Ni)	0.001	0.001
Copper Nickel (70% Cu, 30% Ni)	None	None
Copper Nickel (55% Cu, 45% Ni)	0.002	0.001
Monel (30% Cu, 67% Ni)	0.005	0.003
Nickel*	0.059	0.043

* Test terminated after 497 days.

Observations of the effects of barnacles in inducing local attack of susceptible materials have shown that dead barnacles are more active than live ones. It seems likely that the decomposition products of the barnacles, and particularly sulfur compounds that are formed during decomposition, are responsible for the greater effects of the dead barnacles.

The tendency for pitting of copper nickel alloys to slow down with time, as already mentioned in connection with the 70:30 copper nickel alloy, has also been observed with alloys of higher nickel content. For example, some fifty-odd specimens of Monel in all the common mill forms have been exposed in flowing sea water at the plant of the Ethyl Dow Chemical Company, Wilmington, North Carolina, for a total of 806 days. All of these specimens acquired thick coatings of barnacles and other marine growths. The maximum depth of pitting after the first 168 days' exposure period was 0.010 inch. After exposure for an additional 638 days' period the maximum pitting of the same specimen was only 0.015 inch. In other words, the depth of pitting increased only 50 per cent in about four times the original exposure period.

In the case of alloys containing more than about 40 per cent nickel, the most favorable conditions with respect to the avoidance of local attack include exposure to salt water under conditions where the surface of the alloys remains clean, that is, free from barnacles or other adhering solids. The desired clean surface may result from steady or frequent contact with salt water at relatively high velocity, as in the case of condenser tubes, propeller shafts and underwater boat fastenings and fittings, or in the case of moving parts of machinery, such as pump shafts and the like. In such applications the superior mechanical properties of the higher nickel content alloys, such as Monel and "K" Monel are advantageous.

In the case of alloys containing less than 40 per cent nickel a clean surface is more readily maintained because of the antifouling characteristics of the alloy. However, as the nickel content is reduced much below 30 per cent, the alloy may not be adequately resistant to the effects of high velocity or some other type of local attack, such as water line attack to be discussed.

Waterline Attack.

It has been observed frequently, both in the laboratory [15] and in practice, that when certain metals and alloys are partially immersed in salt water, accelerated corrosion occurs in the waterline region. The attack is not confined to the exact line marking the interface between the liquid and the atmosphere above it, but may occur either slightly above, or slightly below, the waterline. The mechanism of the effect probably includes metal ion concentration cell action induced by discontinuities in corrosion product films in the waterline region and at cut edges.

A practical problem connected with waterline attack provided an opportunity to study the behavior of some nickel copper alloys in comparison with other materials under such conditions of exposure.

Some years ago the U. S. Coast Guard increased the power in motor life boats to an extent that made it possible for these boats to operate to some extent as ice breakers. To provide for such conditions of operation, it became necessary to protect the underwater parts of the wooden hulls by applying metallic sheathing.

The conditions under which the life boats were moored for relatively long periods evidently were very severe so far as waterline corrosion was concerned, since the copper sheathing originally used became perforated in the region of the waterline in as short a period as four months.

The study of this problem included the exposure of a number of test specimens which were suspended from rafts so that they were partially immersed in the sea water. In addition, several materials were applied as sheathing on the boats on which waterline corrosion had been experienced.

Severe waterline attack on copper was reproduced in the corrosion testing program. The behavior of the nickel copper alloys in the same tests showed that waterline and edge attack decreased as the nickel content was raised and was insignificant in alloys containing 30 per cent nickel or more. At the same time, the practical trials of the 70 per cent copper, 30 per cent nickel alloy as sheathing confirmed the indications of the corrosion tests. Similar practical trials of copper coated with various metallic and non-

metallic materials, the common brasses and galvanized iron, established that none of these materials would be suitable.

Although the testing program had shown that nickel copper alloys containing more than 30 per cent nickel were adequately resistant to waterline attack, it was decided to concentrate further attention on the 70:30 alloy, since this composition had the additional advantage of being anti-fouling.

The first boat to be sheathed with the 70:30 copper nickel alloy was put into service in 1935. It is still in service after over five years, whereas the materials formerly used rarely lasted more than a year, and frequently failed in a much shorter time. A large number of these boats have been equipped with 70:30 sheathing during the past few years. Recent inspections of some of the oldest copper nickel alloy sheathing [16] revealed only a slight etching at the waterline, and the sheathing appeared to be good for several years more service.

A typical Coast Guard boat showing the 70:30 copper nickel sheathing fastened to the planking by means of screws of the same composition is illustrated in Figure 3.

Dezincification.

The nickel copper alloys used most frequently to resist corrosion by sea water contain little or no zinc and are, therefore, obviously not subject to dezincification.

Nickel forms a complete series of single phase solid solution alloys with copper throughout the whole range of nickel content. The absence of more than one phase in these alloys, therefore, eliminates local galvanic cell action between phases of different composition which is believed to play an important part, at least in the initiation of dezincification in brasses.[17]

The dezincification type of corrosion reaction involves the accumulation of copper, either as a relatively uniform layer, or as a local spot or plug. It has been suggested that the accumulation of copper results from electrolytic deposition of copper from the products of corrosion of the alloy as a whole.[5, 18] Such re-deposition of copper is favored when the alloy itself is less noble than copper. The nickel copper alloys are slightly more noble than copper in sea water and, consequently, as C. F. Nixon [19] pointed

FIGURE 2.—EFFECT OF NICKEL CONTENT ON THE FOULING CHARACTERISTICS OF NICKEL COPPER ALLOYS IN SEA WATER.

FIGURE 3.—U. S. COAST GUARD MOTOR LIFE BOAT SHEATHED WITH 70 PER CENT COPPER, 30 PER CENT NICKEL ALLOY.

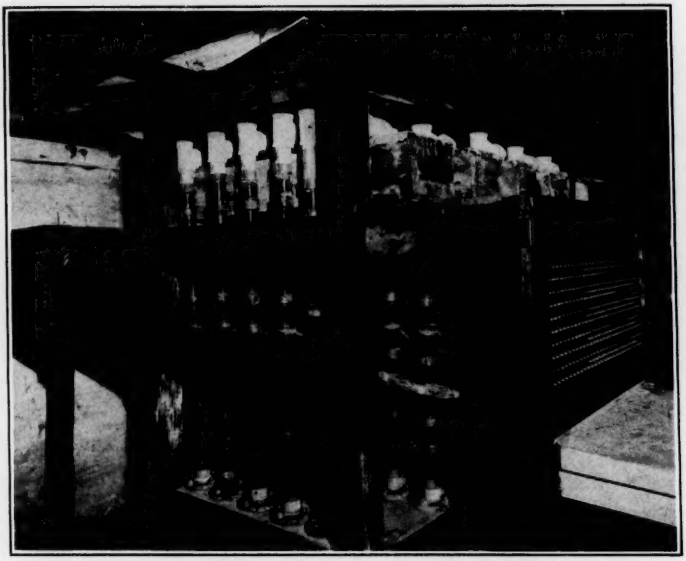

FIGURE 4.—APPARATUS FOR STUDYING THE GALVANIC RELATIONSHIPS AMONGST METALS AND ALLOYS IN FLOWING SEA WATER.

out, these alloys undergo no action comparable to the dezincification of brass. Nixon subjected specimens of Monel to the tests used in studying dezincification of brass and in no case did selective corrosion take place.

As a matter of fact, Nixon found that when from 4 per cent to 6 per cent nickel was added to a brass containing copper and zinc in the ratio of 60:40, no dezincification occurred under conditions of test which produced the effect in the alloy without nickel. Similar tests by this investigator established that a nickel silver alloy containing 64 per cent copper, 18 per cent zinc and 18 per cent nickel—one of the most common varieties of nickel silver—was not susceptible to dezincification.

The alloy known as Ambrac which contains about 75 per cent copper, 20 per cent nickel and 5 per cent zinc has been used more than any other of the copper nickel zinc alloys in sea water service, particularly for condenser tubes.[20] No cases of dezincification type corrosion of this alloy have been encountered.

In connection with the broad subject of the effect of zinc content on the performance of copper nickel alloys in sea water, it should be noted that there is a strong tendency, especially abroad, to limit the zinc content of the common 70 per cent copper, 30 per cent nickel alloy condenser tubes. This restriction on zinc is concerned not with dezincification as such, but rather with possible detrimental effects of zinc on the overall performance of the tubes in condenser service.

Galvanic Relationships.

It is rarely practical to use a single metal or alloy for the fabrication of a complete unit which is to resist corrosion by sea water. The general usefulness of a metal or alloy is influenced, therefore, to an important extent by its behavior when used in galvanic contact with ordinary iron and steel, which usually form the greater part of large structures, or with other corrosion resisting metals and alloys in common use for vital components.

The galvanic relationship amongst metals and alloys is determined primarily by the positions of the several materials in a galvanic series. Such a series, based on several studies of galvanic effects in sea water and similar solutions, was set up in a recent paper.[21]

For convenient reference, this series is repeated here as Table 11.

The arrangement of several of the metals and alloys in the galvanic series shown in Table 11 was based principally on observations made on specimens in the form of pipe nipples through which sea water was pumped for long periods. Means were provided for determining the potentials of the several metals and alloys with reference to a standard calomel half cell, and also for measuring the current generated in a number of typical galvanic couples, especially those likely to be encountered in piping and valve assemblies. This test assembly is illustrated in Figure 4; for a complete description of the set-up the reader is referred to the original paper.

FIGURE 5.—POTENTIALS OF METALS AND ALLOYS IN FLOWING SEA WATER.

For convenient reference, Figure 21 from that paper is reproduced here as Figure 5, which constitutes an arrangement of metals and alloys in a galvanic series from left to right with the maximum, minimum and average observed values for each material being indicated. This method of presentation shows the probable direction of galvanic effects, and also indicates which materials overlap so that variations in the direction of galvanic current flow

TABLE 11.

GALVANIC SERIES FOR SEA WATER.

Magnesium
Magnesium Alloys

Zinc
Galvanized Steel or Galvanized Wrought Iron

Aluminum 52SH
Aluminum 4S
Aluminum 3S
Aluminum 2S
Aluminum 53ST
Alclad

Cadmium

Aluminum A17ST
Aluminum 17ST
Aluminum 24ST

Mild Steel
Wrought Iron
Cast Iron

Ni-Resist

13% Chromium Stainless Steel, Type 410 (Active)

50-50 Lead Tin Solder

18-8 Stainless Steel, Type 304 (Active)
18-8-3 Stainless Steel, Type 316 (Active)

Lead

18-8 Stainless Steel, Type 304 (Active)
18-8-3 Stainless Steel, Type 316 (Active)

Lead
Tin

Muntz Metal
Manganese Bronze
Naval Brass

Nickel (Active)
Inconel (Active)

Yellow Brass
Admiralty Brass
Aluminum Bronze
Red Brass
Copper
Silicon Bronze
Ambrac
70:30 Copper Nickel
Comp. G Bronze
Comp. M Bronze

Nickel (Passive)
Inconel (Passive)

Monel

18-8 Stainless Steel, Type 304 (Passive)
18-8-3 Stainless Steel, Type 316 (Passive)

may occur. In connection with this latter point, however, it should be noted that in most cases changes in the potentials of the metals and alloys were similar in direction and extent so that even though the potential of each material fluctuated, the potentials relative to each other remained fairly constant. The most important exceptions were in the cases of the stainless steels which may, therefore, exhibit erratic behavior with respect to their galvanic relationships towards other metals and alloys, including the nickel copper alloys.

Referring again to the galvanic series (Table 11), the general tendency in any galvanic couple is for the corrosion of the material higher in the series to be accelerated and that of the material lower in the series to be retarded. The intensity of the galvanic effect is determined by the potential developed by the galvanic couple, by the polarization characteristics of the metals, and by several other factors. One of the most important of these is the relationship between the exposed areas of the metals forming the couple. This factor and others, including the resistance of the galvanic circuit, were discussed in considerable detail in a recent paper by W. A. Wesley.[22] It will suffice to state here with respect to the effects of relative areas that it is generally unwise to combine materials where the area of the material higher in the galvanic series is relatively small compared to that of the material lower in the series. The reverse relationship is not likely to be troublesome. For example, Monel bolts are used regularly for joining cast iron flanges on submerged condenser coils without any significant acceleration of the corrosion of the cast iron. On the other hand, a steel bolt or rivet used to join Monel plates would have a relatively short life when immersed in sea water.

The relative nobility of Monel is frequently advantageous where this alloy is used for highly stressed or vital parts of assemblies made up of less noble non-ferrous or ferrous materials having a greater exposed area than the monel and where, therefore, the normally good corrosion resistance of monel is enhanced by protective galvanic effects which, at the same time, are not destructive to these other materials. Typical examples of such applications include Monel bolts, pump and propeller shafts, valve seats and stems, and springs used in conjunction with relatively large areas of bronze, steel or iron.

The metals and alloys listed in Table 11 have been divided into groups. Materials may change places within any group depending on the incidental conditions of exposure. Likewise, galvanic effects in combinations of materials with others in the same group are not likely to be appreciable, especially where the exposed areas of the metals are approximately equal. It will be noted that the nickel copper alloys, with the exception of Monel, are located in the same group as the common brasses and bronzes and that Monel is located not far below this large group of materials. It is also noteworthy that the 70:30 copper nickel alloy lies very close to the Comp. M* and G† Bronzes which are frequently used for valves and fittings in conjunction with copper nickel piping. The suitability of such combinations was also indicated by Noyes in the paper referred to previously [8] and has been confirmed by practical experience.

The close relationship between the nickel copper alloys and the common brasses and bronzes is useful in establishing the probable behavior of the nickel copper alloys in many galvanic combinations, since past experience with bronzes may be used as a reliable guide in estimating the galvanic effects of the nickel copper alloys in instances where the nickel copper alloys may be used to replace a bronze composition.

Although the present trend in condenser construction is towards the use of nickel copper for tube sheets, as well as tubes, it has been common practice to install nickel copper tubes in Naval Rolled Brass tube sheets. From the positions of these alloys in the galvanic series, it would be expected that the tendency would be for the corrosion of the nickel copper tubes to be retarded and that of the brass tube sheets to be accelerated. This is a desirable direction for the galvanic effects, since the tubes are much thinner than the tube sheets and are subjected to more drastic corrosive action. In many instances, also, such combinations of nickel copper alloy and brass have been used in conjunction with unpainted cast iron water chests which have provided galvanic protection and

* Comp. M approximately 88 per cent Cu, 6.5 per cent Sn, 4 per cent Zn, 1.5 per cent Pb.

† Comp. G approximately 88 per cent Cu, 10 per cent Sn, 2 per cent Zn.

thereby neutralized any local galvanic effects between tube sheets and tubes. Similar protection has been afforded by the use of zinc or steel protector plates in the water chests.

R. May [10] has mentioned that the beneficial effect on condenser tube life of steel protector plates in water chests is greater than might be expected from simple galvanic effects. In this connection, it was suggested that the presence of iron compounds in the water assists in the building up and maintenance of protective films on the condenser tubes. At any rate, analyses of films from tubes which have performed exceptionally well have disclosed the presence of appreciable amounts of iron. It has, therefore, been suggested that the use of iron protector plates should still be considered seriously, especially where there is no opportunity for solution of iron from water boxes.

It will be noted also, that the use of lead tin alloy coatings on condenser heads or water chests may be expected to reduce rather than accelerate the corrosion of copper nickel alloy tubes and brass tube sheets.

In summary, it may be said that the nickel copper alloys can ordinarily be used in galvanic contact with other copper alloys and copper without the development of serious galvanic effects. In combinations with ordinary steel or iron, the copper nickel alloys will act about the same as other copper alloys so far as the extent of acceleration of corrosion of the iron is concerned. Some typical data which illustrate this latter point are given in Table 12 from which it will be seen that there is no considerable difference amongst nickel, copper, and two common nickel copper alloys with respect to their tendency to cause accelerated corrosion of cast iron. It may also be noted that all of these materials are given practically complete protection from corrosion by sea water when they are coupled galvanically with an equal area of cast iron.

TABLE 12.

RESULTS OF EXPOSURE OF GALVANIC COUPLES OF CAST IRON WITH OTHER MATERIALS COMPLETELY IMMERSED IN SEA WATER AT EASTPORT, MAINE, FOR NINE MONTHS.

Area of all specimens in couples — 0.5 sq. dm.

Couple	*Rate of Corrosion of Cast Iron in Inch Penetration Per Year*	*Rate of Corrosion of Other Metal in Couple in Inch Penetration Per Year*
Cast Iron—Uncoupled....	0.010	.....
Cast Iron with Copper....	0.027	0.00004 (Copper)
Cast Iron with 70% Copper, 30% Nickel Alloy	0.025	0.00008 (70:30 Cu Ni)
Cast Iron with Monel (67% Ni, 30% Cu)....	0.025	0.00001 (Monel)
Cast Iron with Nickel....	0.025	0.000006 (Nickel)

As is the case with other relatively noble, corrosion resisting metals or alloys, the nickel copper alloys should not be used in combination with materials higher in the list given in Table 11 under circumstances where the exposed area of the less noble material is relatively small as compared with that of the copper nickel alloy unless, of course, accelerated corrosion of the less noble material may be tolerated, or is expected, as in the case of zinc or iron protector plates.

MISCELLANEOUS OBSERVATIONS.

1. Effects of Mill Scale.

Tests and practical experience have shown that the scale formed on nickel copper alloys at elevated temperatures—as in hot rolling, annealing, or other heat treatment in an oxidizing atmosphere—does not tend to accelerate corrosion in sea water even in cases where the scale may be discontinuous. As a matter of fact, hot rolled Monel with the mill scale present is somewhat superior to the pickled or ground material from the standpoint of resistance to sea water corrosion. Similar observations have been made with

respect to the thin scale which is formed on "K" Monel when it is heat treated in an oxidizing atmosphere; it is not necessary to remove this heat treating scale in order to insure good resistance to sea water corrosion.

In the case of condenser tubes, it is, of course, standard practice to provide tubes having a smooth, scale free surface.

2. Effects of Form.

It has been observed in connection with corrosion tests and in the practical application of the alloy that Monel in the form of rods, bars and shafts, and parts such as bolts fabricated from these forms, is appreciably better than when it is in the form of sheets or other flat rolled products, with respect to resistance to sea water corrosion, especially under conditions that tend to favor local attack, such as continuous immersion in stagnant or slowly moving sea water and where marine organisms may become attached to the metal surfaces.

3. Effects of Minor Constituents.

Tests on several lots of Monel have disclosed that such common minor constituents as iron, manganese, silicon and carbon have no important effect on corrosion resistance within the ranges normally encountered. Similarly, it has been found that there is no significant difference between "K" Monel, "S" Monel, "H" Monel and regular Monel with respect to their behavior in sea water. However, where cavitation is a factor, the harder alloys ("K" Monel and "S" Monel) have advantages which are due principally to mechanical rather than chemical factors as demonstrated by tests reported by S. L. Kerr.[23] Incidentally these tests also indicated that in the nickel copper series resistance to cavitation erosion increases as the nickel content is raised. Pertinent data from Kerr's paper have been abstracted in Table 13.

Tests are under way to study the effects of minor constituents, principally iron and manganese, on the ability of the 70:30 copper nickel alloy to resist impingement effects and other types of sea water attack. Results already available are in good agreement

TABLE 13.

RESULTS OF CAVITATION EROSION TESTS IN SEA WATER BY THE VIBRATORY METHOD.

Material	*Weight Loss During Last 60 Minutes of Test in Milligrams*
Copper	175
30% Nickel, 70% Copper Alloy	87.6
44% Nickel, 54% Copper Alloy	74.6
67% Nickel, 30% Copper Alloy (Monel)	53.2
66% Nickel, 29% Copper, 2.75% Aluminum Alloy ("K" Monel)	24.7
63% Nickel, 30% Copper, 4% Silicon Alloy ("S" Monel)	21.4

with those of similar tests and practical experience abroad. They indicate that the minimum iron content should be about 0.3 per cent and that the manganese content should exceed the iron content. There has been no evidence that such common upper limits on iron and manganese as 0.50 per cent and 1.00 per cent respectively, need be changed.

On the basis of a comparison of nickel copper alloy tubes which had shown differences in their response to the operation of rolling into tube sheets and supplementary cold workability and mechanical tests, J. A. Duma [24] concluded that whenever the copper content was much in excess of 70 per cent, the tensile and cold forming properties would be found to be inferior to those possessed by an alloy, the copper content of which was not in excess of 70 per cent. He also indicated that the usual minor constituents in the proportions normally present tended to decrease the detrimental effects of copper so that up to 80 per cent of copper might be tolerated without serious effects on ductility.

Duma also reported that tubes which had a high percentage of copper oxides in their structure were likely to fail by splitting during belling and expanding operations. Tests in a mercurous-nitrate solution showed that tubes which contained appreciable amounts of copper oxides were pitted, while those which were oxide free suffered neither pitting nor cracking even when tested in a highly stressed condition.

Tests in boiling sea water which was allowed to cool for 16 hours out of each 24 showed that corrosion was more lateral than penetrating, and more general than local. Corrosion also served to disclose minute cracks on the rims of the belled specimens. There was also evidence that the most highly stressed areas had undergone the most corrosion.

The insoluble corrosion products which formed on the surfaces of the specimens consisted principally of copper compounds.

4. Effects of Welding.

Numerous tests on welded nickel copper alloy specimens in various forms, and practical experience with welded structures of the commonly used nickel copper alloys in sea water service, have established that the corrosion resistance of welds formed by gas welding, arc welding or resistance welding methods is equivalent to that of the parent metal. Likewise, there has been no evidence of any detrimental effects of the heat of welding on the corrosion resistance of the material in the vicinity of welds.

It may be noted, also, that several of the racks used by the author in connection with the exposure of specimens to corrosion by sea water were fabricated from hot rolled 70:30 copper nickel alloy angles joined by metallic arc welding with Monel welding rod. Careful examination of these welds and the adjacent metal after the racks had been immersed in flowing sea water for nearly four years showed no evidence of appreciable corrosion.

5. Effects of Temperature.

Most applications of metals and alloys in sea water service involve contact with the water at temperatures not much above atmospheric. However, in some instances, higher temperatures may be encountered, especially in connection with condensers or

heat exchangers in which the 70 per cent copper, 30 per cent nickel alloy is most commonly used. In this connection, R. A. Wilkins [20] has emphasized the particular advantages of the nickel copper alloy tubes where operating temperatures are in excess of 100 degrees F. Under such operating conditions other copper alloy condenser tubes have been found to be definitely inferior to the nickel copper alloys.

SUMMARY.

The data which have been presented were chosen to illustrate in as general a way as possible the outstanding characteristics of nickel copper alloys with respect to their behavior in sea water. In applying such data to the choice of an alloy for a particular purpose, it is necessary, as was pointed out previously, to consider as well such factors as physical and mechanical properties, availability in the required forms, cost and practical experience. Experience tends in time to integrate all the important factors and for this reason there is appended in Table 14 a list of practical applications of the nickel copper alloys—Monel, 70:30 copper nickel and nickel silver—which have been used most extensively in marine engineering. It is hoped that this list will serve as a useful guide to the choice of the proper alloy for specific purposes.

TABLE 14.

PRACTICAL APPLICATIONS OF NICKEL COPPER ALLOYS IN MARINE ENGINEERING TO RESIST CORROSION BY SEA WATER.

	HULL
Application	*Alloy*
Airports and Hull Rings	Monel
Anchors	Monel and "K" Monel
Decorative Trim	Nickel Silver and Monel
Fastenings—bolts, screws, nails, etc.	Monel (See Fig. 6)
Flooring—non-slip	Monel
Galley Equipment	Monel
Insect Screens	Monel

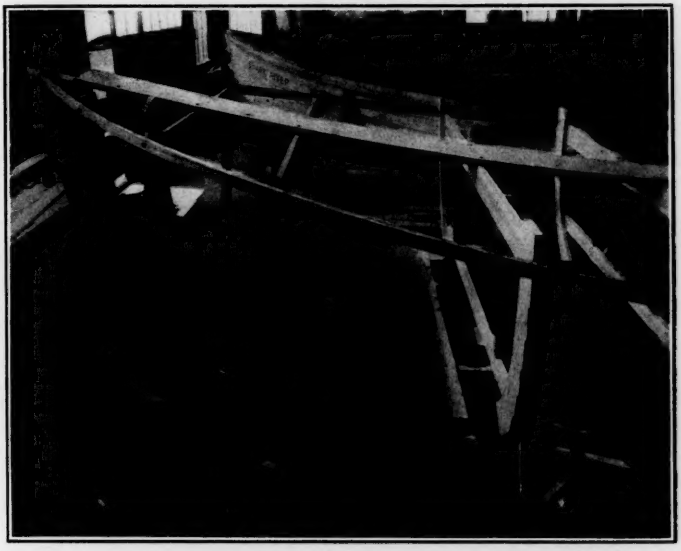

FIGURE 6.—MONEL FASTENINGS AND RUDDER PINTLE IN SMALL BOAT CONSTRUCTION.

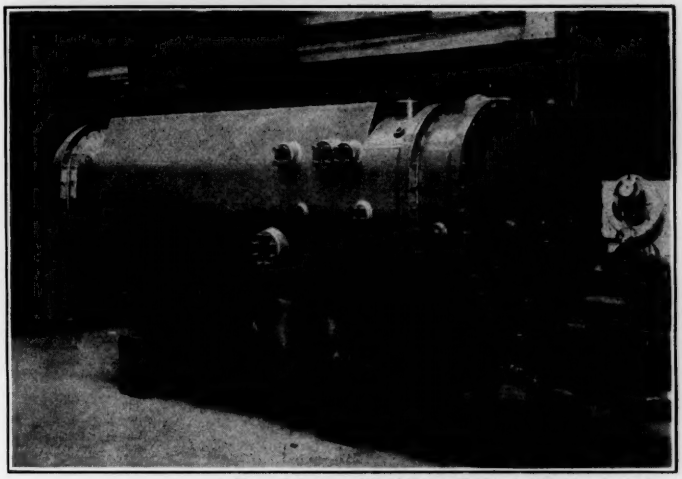

Photo Courtesy: Worthington Pump & Machinery Corp.

FIGURE 7.—CONDENSER FITTED WITH 70:30 COPPER NICKEL TUBES AS USED BY U. S. MARITIME COMMISSION IN C. C. CARGO VESSELS.

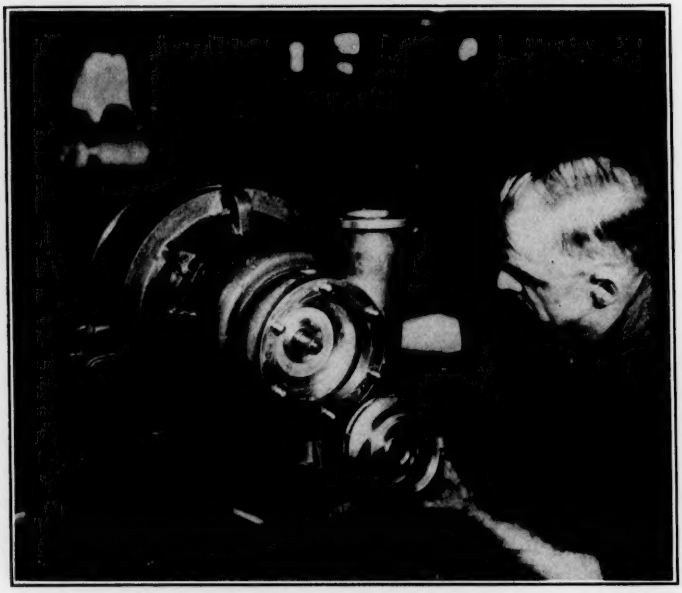

FIGURE 8.—BRONZE SALT WATER PUMP WITH MONEL IMPELLER, MONEL STUDS, "K" MONEL SHAFT AND WEARING SLEEVE.

Instrument Panels	Monel
Piping (Salt Water)	70:30 Copper Nickel
Plumbing Fixtures	Nickel Silver
Refrigerator Linings	Monel
Rudders and Rudder Fittings	Monel
Sheathing	70:30 Copper Nickel
Struts	Monel
Tiller Rope	Monel
Trawler Hold Linings	Monel and Nickel-Clad Steel
Valve Seats and Discs	Monel and "S" Monel
Valve Stems	Monel
Wash Basins	Monel
W. C. Troughs	Monel
Water Tanks—Life Boats	Monel

MACHINERY

Condensers (Main & Auxiliary)	
Tubes (See Fig. 7)	70:30 Copper Nickel, 80:20 Copper Nickel and Monel
Tube Sheets	70:30 Copper Nickel
Water Chests	Monel and 70:30 Copper Nickel
Flange Bolts	"K" Monel
Distillers and Evaporators	
Tubes and Tube Sheets	70:30 Copper Nickel
Instrument Parts (Non-Magnetic)	"K" Monel
Messenger Cable	Monel
Mufflers (Gasoline Engine)	Monel
Oil Coolers	
Tubes and Tube Sheets	70:30 Copper Nickel
Piping (Salt Water)	70:30 Copper Nickel
Pressure Lubrication Fittings	Monel and "K" Monel
Propeller Nuts and Caps	Monel
Propeller Shafts	Monel

Pumps (Centrifugal)
(See Fig. 8)
Impellers ..... Monel
Shafts ..... Monel or "K" Monel
Shaft Sleeves ..... "K" Monel
Pumps (Portable-Submersible)
Shafts ..... Monel
Pumps (Propeller)
Impellers ..... Monel
Shafts ..... Monel or "K" Monel
Shaft Sleeves ..... "K" Monel
Turbine Shafts ..... "K" Monel (If Close Coupled)
Pumps (Reciprocating)
Liners ..... Monel
Rods ..... "K" Monel
Studs ..... Monel
Valves ..... Monel
Pumps (Rotary) .....
Shaft Sleeves ..... "K" Monel
Strainers ..... Monel
Thermometer Sockets ..... Monel
Valve Seats and Discs ..... Monel and "S" Monel
Valve Stems ..... Monel

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EVALUATING WELDING ELECTRODES.

By Joseph A. Duma.*

The author presents data collected to discover the physical and chemical properties of good welding electrodes and to provide material for discovering a quantitative formula for evaluating electrode qualities. In the text he describes how the data yielded the results desired.

The excellence of manual arc welding processes is fundamentally dependent upon operator skill and electrode material. Skill, industrially defined, consists of acquired tendencies to act in established and not random ways. After these tendencies are made perfect by constant repetition, further improvement in the science and art of welding must needs come from better electrode material.

Because the two are so intimately interrelated, isolating skill from electrode quality is admittedly a most difficult task. Though some isolation of factors has been achieved in the present study, no especial effort was made in that direction. Separation of the two is deemed neither essential nor necessary. What is needed is a formula for integrating material and welder skill, i.e., one which grades relatively electrode performance under conditions of varying skill.

Arranged in chronological sequence, the accompanying tables are, in a manner of speaking, a tabular treatise on the metallurgical metamorphosis of ten commercially popular welding electrodes,—each brand of electrode highly individualized as to chemical composition and highly specialized as to details of manufacture. They give a quantitative evaluation of the phenomena attending the transformation of ten different brands of flux coated wire to an equal number of slag covered, arc-cast metals.

* Associate Metallurgist, Norfolk Navy Yard.

The subject data were collected with two primary considerations in view: first, the discovery, by analysis, of the physical and chemical nature of the materials which are being employed in the manufacture of the better grades of electrodes; and second, the formulation of a quantitative formula for the evaluation of electrode quality. It is believed that the first objective has been realized. Coating mixes for an all-position electrode have been prepared on the basis of the subject findings and have been field-tested with results comparable to those obtained on the best commercial electrodes made. The second objective has also been attained. The formula for qualitatively grading electrode performance is given in Footnote 37, in the Tables, and its use is illustrated in a later paragraph.

To save time and expense, all testing was done in the vertical position. Records of Welders' Annual Qualification Tests show that this is the position in which it is most difficult for a welder to obtain a sound, ductile weld. It is generally conceded that an electrode that welds satisfactorily in the vertical position will also weld with equal satisfactoriness in the overhead, horizontal, and flat positions.

The following interpretative remarks are offered on the data contained in the Tables. For ready reference, the data is arrayed under the following headings and in this order: Core Wire, Coatings, Slag, Weld Deposit, Field Tests, Oscillograms, and Arcronograms.

Core Wire.

(1) The telltale elements, silicon and manganese, betoken the source and method of manufacture of electrode steel, i.e., rimmed ingot deoxidized with ferro-manganese.

(2) Fragmented sonims in core wire indicate brittle oxide-silicate compounds; unbroken sonims are probably the more ductile sulphides. Sulphide impurities, according to good authority, are the most prolific source of gas explosions and high spatter losses. Due to the masking effect of other influences, the Tables fail to show any correlation between depth or number of slag explosion craters and sulphur content.

(3) Observe the nice relation existing between tensile strength, degree of cold work, and grain elongation.

(4) The McQuaid-Ehn grain size appears to indicate a comparatively low occluded oxygen content (.02-.05 per cent) in all ten electrodes.

(5) String beads laid with the core wires stripped of their coating—using straight polarity, same base plate, amperage, welding machine and welder—showed considerable variation with respect to penetration, ripple contour, and general appearance. The reason for this is not known. Wires having a grain size in excess of 100 grains per square inch at 100X gave rough appearing beads.

Coatings.

(1) No definite information regarding the age of the electrodes is had. Inasmuch as the subject tests were made on newly purchased material, it is assumed that the manufacturer furnished fresh material.

(2) Having been exposed to approximately 350-400 degrees F. of heat, half-consumed electrodes are generally drier, and therefore harder, than whole, unused electrodes. This may be the reason for the higher shear strength of half-consumed electrodes.

(3) On basis of chemical composition, the ten coatings are classified as follows:

Gas-Shielded		*Slag-Shielded*	
Brand No.	*Type*	*Brand No.*	*Type*
1, 2, 3, 4, 7, 9	.....	5	High Mn. Oxide
6, 8	High Titania	10	High Iron Oxide

(4) In ounces of metal deposited per hour, the high titania brands show the highest melting rate. The low arc voltage of the high titania brands denotes a high thermionic emissivity.

(5) The volatile per cent values reveal the relative volumes of shielding gases evolved from carbo-hydrate coating materials (paper, cotton, wood flour, cellulose-acetate, starch, dextrin, etc.).

(6) Concerning moisture, it appears that electrodes, having once been dried, gradually regain their lost moisture on subsequent exposure to the atmosphere.

Electrode Slags.

(1) The slags are all basic in character. Electrode No. 7 produced the most basic slag, electrode No. 8 the next most basic, and then electrode No. 6. Basic slags slightly reduce the oxygen and silicon content. Slags high in FeO lower not only the silicon, but also the manganese content. Basic slag reactions are more prone to develop "flaky" or bird-eye deposits than acid slag reactions.

(2) The greater the amount of slag produced per electrode the lower is the deposition efficiency.

(3) The greater the amount of slag produced per gram of coating material the greater is the deoxidizing power of that material.

(4) Glassy slags contain better than 25 per cent silica; blue slags carry from 12 to 17 per cent manganese oxide; gray slags owe their color chiefly to a high content of titanium dioxide (in excess of 30 per cent).

(5) Thick slags, i.e., slag-shielded electrodes, produce deposits which are nearly free from the defect known as "bird-eyes."

Weld Deposit.

(1) It is the contention of some electrode manufacturers that the aging of test specimens after machining benefits ductility. A study of the elongation values of aged and unaged specimens reveals that out of ten specimens four showed a decrease and six a slight increase in elongation.

(2) Regarding elongation, only four specimens out of a total of forty passed the 22 per cent minimum elongation requirement of Specifications 22W7(INT). Electrodes No. 5 and No. 10, both of the slag-shielded type, gave the above four specimens. The failure to meet ductility requirements is traceable to too thick layer deposits, to hindered contraction and shrinkage stresses resulting from the fixity of the joint, and to the presence of the defect, "bird-eyes," in the fractured weld metal,—the last defect, a product of hydrogen embrittlement. Weaving metal layerwise across the Vee in passes 1/16-inch to 1/8-inch deep breaks up completely the cast structure of underlying layers. All other things remaining equal, such structural refinement always results in increased ductility. Using the weaving technique, electrode No. 2—in another test—gave 24 and 25 per cent elongation values.

(3) According to Sauveur,[1] the theoretical elongation values for steel containing .10 and .15 per cent carbon in the fully annealed condition are 45.3 and 43.0 per cent, respectively, in two inches. Providing the metal has not been embrittled with gasses, slag trappings, or excessive shrinkage and cooling stresses, approximately two-thirds, and not one-third, of this elongation value should be realized. It is believed that the low ductility of weld deposits made with electrodes having a cellulosic covering is due to the absorption of large volumes of atomic hydrogen by the molten metal. Larson[2] has found that the quantities of various gases liberated by one centimeter of a ¼-inch covered electrode of the above type are as follows: Hydrogen, 85.4 cubic centimeters; carbon monoxide, 70.3 cubic centimeters; water vapor, 9.3 cubic centimeters; carbon dioxide, 1.9 cubic centimeters (all measured at 100 degrees C. and 760 millimeters pressure). Thus the total volume of gases generated is approximately 300 times the volume of electrode consumed when measured at 100 degrees C. In open hearth and electric furnace practice such large quantities of hydrogen would never be tolerated. It has been found that the hydrogen present in the form of moisture in furnace fluxes and even the moisture in the air affect deleteriously the ductility of the metal. Countless experiments and practical observations alike have demonstrated that the strongest steel is amenable to defects caused by this gas. This defect has several aliases: in forgings it is recognized as "flakes"; in rails it passes under the cognomen of "fissures"; in rolled sheet it is known as "blisters"; in castings, as "white spots"; and in weld deposits, either as "bird-" or "fish-eyes." Each is the result of hydrogen retained locally in discontinuities.

(4) Observations confirming the sameness of the mechanism of flake and bird-eye formation are:

(*a*) Weld metal laid with slag-shielded (low gas forming) electrodes rarely discloses any bird-eyes in its tensile fractures, even though it has been deposited with the same technique as gas-

[1] Sauveur, "The Metallography and Heat Treatment of Iron and Steel."
[2] L. J. Larson, "Metallurgical Aspects of Welding," Metal Progress, December, 1938.

shielded electrodes. Bare wire deposits as well as Union-Melt welds, for the same reason, are practically bird-eye free.

(*b*) Bird-eyes have been eliminated from weld metal with the same method as is being employed in the elimination of flakes from steel, namely, low temperature aging, i.e., 10 to 15 hours at 450 degrees F., which influences the movement and diffusion of the so-called mobile elements such as hydrogen, oxygen, carbon, and nitrogen. The mechanism of hydrogen diffusion (whereby irreversible transformations become partially reversible) is described in a correlated abstract on "Hydrogen, Flakes and Shatter Cracks" in recent issues of Metals and Alloys (May, June, July, and August) by Zapffe and Sims.

(5) It is therefore believed that bird-eyes are caused by internal pressure built up by hydrogen precipitated in discontinuities (small voids, micro-shrinkage, grain boundaries and the disjunctions of interfering dendrites and neighboring crystalline units, and points of weakness such as the interfaces of inclusions where there may be a lack of contact between inclusion and metal occasioned by unequal shrinkage and cooling). Theoretical calculations have indicated that very high aerostatic stresses can be developed in this manner. Ordinarily the pressure of the hydrogen is not great enough to rupture the steel without aid. The additional, contributory stresses which help produce ultimate rupture of hydrogen-stressed areas are shrinkage and cooling stresses or externally applied mechanical stresses.

(6) The McQuaid-Ehn structures of weld deposited metal indicate presence of excess dissolved oxides. The structure of carburized specimens is predominantly abnormal, consisting largely of either heavy ridges of cementite in masses of ferrite or blotchy, ill-defined, broken lines of cementite at the crystal boundaries. Small areas of normal structure were also found in nearly all specimens.

(7) Deposition rate does not always vary directly with the current.

(8) Deposition efficiency appears to vary inversely as the welding current. High welding currents impair melting efficiency because of increased metal spatter and vaporization losses. On

the average, the lower welding current yielded slightly better ductility values. On the other hand, Welders' Annual Qualification Tests seem to indicate that skillful high heat welders are more consistent and obtain more ductile welds than low heat welders.

(9) Electrode performance is a summation of the following combinations of physical values:

(a) $$\frac{\text{Per Cent Elongation} \times \text{Tensile Strength}^{(1)}}{10{,}000}$$

(b) $$\text{Per Cent Bends Passed} \times 2^{(2)}$$

(c) $$\frac{\text{Per Cent 45 Degree Fillets Satisfactory}^{(3)} + \text{Per Cent Appearance of Each}}{4}$$

(d) $$\frac{\text{Manual Current Range} \times 100^{(4)}}{\text{Watts Consumed by Coat}}$$

1. Average of 2 test specimens.

2. Total number of bends = 6; 3 face and 3 root, 1 face and 1 root made by 3 welders possessing different degrees of welding ability; i.e., an outstandingly good welder, a welder of ordinary or average skill, and a welder of less than average ability.

3. Fillets 6 inches long, laid in a 45-degree angle formed by two plates, one galvanized and one black, and each 3/16-inch thick. An electrode is unsatisfactory if at any point the plate has been burned through by a good welder. See note 49 in the Tables for manner of rating appearance.

4. Determined by making Welders' Qualification Root Bend Tests in the vertical position on 3/8-inch steel plate with 3/16-inch root opening.

(10) By way of illustration, performance value on electrode No. 1 was computed thusly:

$$(a)\ \frac{15 \times 72{,}125}{10{,}000} = 108.2$$

$$(b)\ \left(\frac{4}{6} \times 100\right) \times 2 = 133.4$$

$$(c)\ \frac{100 + 100 + 70 + 90}{4} = 90.0$$

$$(d)\ \frac{(150\text{-}90) \times 100}{284} = 21.1$$

Performance Value = 352.7

(11) Using the above formula, the following order of performance value was obtained for the electrodes tested:

Brand No.	*Ave. Per. Value*
4	349.1
1	337.4
2	317.0
7	314.7
9	309.0
6	303.6
5	266.9
8	263.2
3	240.3
10	225.8

(12) Concerning performance evaluation, it is seen that emphasis is laid first on the ductility of the deposit, next on the workability of the electrode in sharply angular recesses, then—coming back to the deposit—on its tensile strength, and on the excellence of its surface. And lastly, on the uncriticalness of the electrode to the production of any physical ill effects in the deposit when being welded with changing values of welding current and arc voltage.

Ductility is desirable in fixed structures to enable them to better absorb plastic movements induced by shrinkage and cooling stresses. It is needed for the readier alignment of members improperly fitted or otherwise constrained; for bending, straightening, and various cold forming operations; for greater resistance to thermal and mechanical shocks. A good electrode must therefore deposit ductile metal,—one that is free from bird-eyes.

A good electrode should also be able to weld satisfactorily in acute re-entrant angles. Unless an electrode is adequately charged with arc stabilizing materials, deeply recessed dihedral angles will distort its arc, causing it to either flare or blow magnetically. Wild arcs are productive of unsound deposits. Corner welding also accentuates the penetrating characteristics of an electrode. A deeply penetrative electrode, when used on corner material of a thickness equal to that of its diameter, will invariably pierce the work even though it be most expertly handled. Such an electrode has a restricted range of application.

The third component in the quality formula is tensile strength. Satisfactory welds, from the standpoint of strength, are those whose yield point and tensile strength equal or exceed that of the base material.

A good electrode must produce a smooth appearing weld, of a specified contour, and free from overlapping and undercutting. The smoothness and number of surface ripples, all other things remaining equal, is a function of metal fluidity, while rolling and undercutting are principally the result of improper electrode manipulation. It is added that an excellent surface not only enhances the value and all-around appearance of a welded structure, but is itself an integral part of the quality of the weld.

One other major requirement for a good electrode is that it have a widely working current range, be not critically sensitive to slight changes in arc voltage, and consume minimum wattage for the burning of its coating.

It will be noticed that deposition rate and deposition efficiency do not appear in the performance equation. This is because they are not constant but fluctuating values which can be varied by wide amounts and almost at will with welding current.

Specific gravity, too, is omitted from the performance equation. In lieu thereof, more ductility figures are used. Ductility is not only a more sensitive indicator of the degree of integrity and soundness obtained in a weld, but is secured at less cost and is easier to measure.

The main intention of the above formula is to evaluate the performance of electrodes. It is not an inspection formula, nor does it dispense with inspection. Tests to determine the following should not be overlooked: length and diameter of wire; dielectric strength, concentricity, ductility and harmful character of fumes of coating; adherence and removability of slag, etc.

Field Tests.

(1) Some of the discrepancies between laboratory and field tests are traceable to differences in base materials, especially galvanizing. Zinc is a serious detriment to welding and its influence on the performance of the electrode and on the quality of the resulting weld should not be overlooked.

(2) Downward welding, it will be noted, takes a higher value of current.

(3) The slag-shielded electrodes No. 5 and No. 10 are deeply penetrative. Excessive penetration such as this causes puncturing of light work, and undercutting. Light galvanized materials especially are prone to piercing by localized melting.

Oscillograms and Arcrograms.

(1) Engineering Experiment Station Report No. B-481, Feb. 16, 1939, sums up the oscillographic studies made on the subject electrodes with a statement to the effect that,—to obtain beads of satisfactory form and contour, it is essential that organic coated, all-position electrodes function with short circuit periods in excess of 1/120 second, and average 6-12 per cent of the total elapsed time per electrode at a frequency of 8-16 per second.

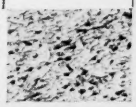
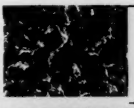
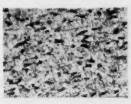
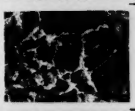
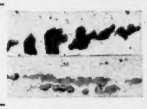
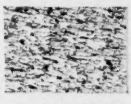
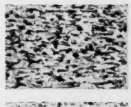
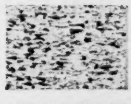
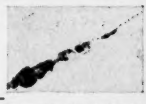
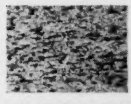
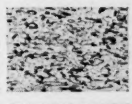
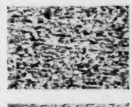
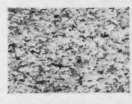
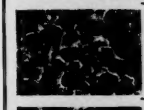
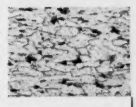
(2) Statements have been appearing in the literature to the effect that aluminum and aluminum oxide are the most effective non-stabilizers causing arc instability when present in less than

CORE ANALYSIS
% Composition

Brand	C.	Mn.	P.	S.	Si.	Cu.	Ni.	Ti.
#1	.09(1) .08	.46	.02	.04	.01	.06	None	None
#2	.10 .12	.43 .46	.02	.02	.01	None	None	None
#3	.11	.46	.02	.01	.01	None	None	None
#4	.14	.46	.02	.03	.01	None	None	None
#5	.12 .08	.45 .46	.02	.03	.01	.12	None	None
#6	.12	.49	.02	.03	.01	None	None	None
#7	.12	.53	.02	.04	.01	.08	None	None
#8	.12 .13	.45 .46	.01	.03	.02	.12	None	None
#9	.08 .08	.40	.01	.03	.01 .02	.03	None	None
#10	.08 .07	.50	.02	.04	.01 .01	.10	None	None

(1) Check analysis was made on a 2nd different rod.
(2) All structures taken on a longitudinal section midway between center and outside.
(3) Detail structure of largest inclusions. Average size and distribution at X100 is shown below.
(4) Ratio of average length of grain to average width of grain.

CORE PROPERTIES

	Microstructure(2)				McQuaid-Ehn Structure(5)
	Unetched X500 (3)	Etched in Nital - X100 (4)	Grns psi/ X100	Ratio L:W (5)	Etched in Nital - X100 Grns psi/ X100
			110	4.0	 16
			80	4.0	 5
			50	9.0	6
			60	6.0	3
			70	9.0	16
			160	3.0	10
			130	3.5	16
			150	3.5	16
			130	3.5	 18
			40	5.0	10

(4) Pearlite in all specimens laminated except that in specimen #6 which is spheroidal as shown directly above at X500.
(5) Standard McQuaid-Ehn Test.

TESTS OF 5/32" COVERED ELECTRO

COATINGS AND THEIR PROPERT

Core Physical Properties							Coat Physical Properties												
As-received				Annealed(7)								Shear Value(10)		Bend - 8" Pin Producing(11)		Al.	Mo.	Fe.→FeO	
T.S. psi	Elong in 1" %	Sp. Gr.	Resistance Ohms	T.S. psi	Elong in 1" %	T.S. due to Cold Working psi	Thickness Inches	Eccentricity Inches	Weight Grams/ Linear Inch	Weight % of Core (9)	No. of Rods in 20 lbs.	As-Rec'd psi	Upper Yield Half psi	Crack Degs.	Flake Degs.				
82,720 80,480	10.0 10.0	7.82		49,480	50.0	32,110	.019	.002	.281	10.6	595	1650	2200	10°	50°	.22	None	2.82	3.25
84,046 87,097	9.5 9.5	7.83	.00450 (8)	45,310	46.0	40,711	.018	.001	.255	10.4	602	2200	2200	10°	45°	Tr.	None	3.30	4.26
91,660 88,503	11.0 12.0	7.81	.00485	47,640	47.0	42,451	.031	.001	.440	17.9	588	823	1650	10°	65°	.16	None	1.85	2.35
91,150 86,979	12.0 11.0	7.81	.00440	49,210	50.0	44,855	.028	.002	.442	17.9	588	1140	1840	12°	75°	.32	None	2.29	2.9
93,710 92,060	11.0 10.0	7.83		50,000	46.0	42,885	.028	.002	.437	17.8	585	582	1140	8°	45°	.31	None	4.48	5.7
78,046 81,611	14.5 12.0	7.81	.00450	48,440	46.0	30,388	.019	.002	.280	11.4	602	783	1480	12°	80°	.65	None	.70	.8
81,150 81,980	10.0 10.0	7.81		51,580	46.0	29,995	.021	.003	.312	12.6	584	1922	2200	12°	80°	.72	None	4.48	5.7
84,375 87,454	9.5 11.0	7.82	.00435	52,440	45.0	33,465	.023	.001	.295	11.9	585	707	1940	10°	75°	.48	None	.56	.7
87,434 89,150	14.0 13.0	7.85		44,790	46.0	41,502	.018	.003	.209	8.5	607	720	1360	13°	120°	.22	None	2.63	3.3
79,930 81,810	9.5 10.0	7.83		44,820	52.0	36,260	.031	.003	.593	24.1	540	653	1280	10°	70°	1.36	None	13.87	17

(7) Annealed at 1500°F for 2 hrs. The object of this treatment was to get a check, with physical properties, on the carbon content; also to determine the amount of cold rolling by noting the difference between the as-received and annealed tensile values. Note their agreement with L=W ratio

(8) Approximately equivalent to 15.8 microhms per cm³.

(9) Weight of 3 core wires (14"long by .1885"dia.) = 103.2710 grams.
Weight of 1 running inch of core wire = 2.4586 grams.
Weight of coats on 1 wire = 2.7 to 7.7 grams.

(10) 3/8" long specimen (see E.E.S. Report No. B-481,Feb.18, 1938).

(11) Navy Dept Spec. 52S7b bend requirement = 60°.
Navy Dept. Spec. 52S7c bend requirement = 30°.

(12) Fe.(Calc
Al.(
Mo.(
Si.(
Ti.(
Cu.(
Mg.(
Zi.(
Alkalies
Alkanity
All comp

Mn.x 1.
Fe.x 1.

R PROPERTIES

No.	Percent Chemical Composition(12) Fe.→FeO		Mn.→Mn_3O_4		TiO_2	CaO	MgO	CO_2	Na_2O	SiO_2	Na_2SiO_3 (41.1°Bé)	Coatings: Volatile 200°C	Volatile 780°C	Volatile 1800°C	Moisture(13) Original --- %	Pick-Up 4hrs %	Pick-Up 20hrs %	Pick-Up 40hrs %	Pick-Up 1800hrs %	Stability in Water(14) Hrs.
None	2.02	3.25	10.68	17.19	12.57	.80	10.39	1.88	3.84	31.69	33.00	8.18	24.80	28.93	7.1	.6	.7	.9	---	96
None	3.30	4.26	10.26	16.51	12.39	.26	7.51	1.08	3.96	31.16	34.04	4.85	24.46	28.32	6.1	3.2	4.1	4.1	4.3	120
None	1.85	2.39	7.15	11.50	14.57	1.71	8.07	1.73	3.29	30.95	37.69	7.30	20.18	29.15	7.8	3.0	5.1	5.2	5.5	84
None	2.99	2.98	7.48	11.68	14.62	1.22	4.12	1.09	3.93	34.09	33.78	7.84	26.31	27.05	7.1	3.4	4.5	4.5	4.6	78
None	4.48	5.70	12.47	19.70	10.86	.25	6.03	.86	2.70	36.79	23.20	6.21	17.36	19.48	6.6	.6	.7	.7	---	60
None	.70	.90	3.38	5.34	20.03	.21	2.85	1.98	2.93	33.97	28.17	9.05	27.64	28.04	7.6	3.8	3.0	3.4	3.4	88
None	4.48	5.78	7.20	11.38	17.80	.25	8.77	1.16	2.81	24.37	24.18	5.35	28.19	28.80	6.1	1.1	1.9	2.1	---	148
None	.56	.72	6.02	9.51	20.46	.14	.37	1.48	4.16	30.99	35.78	8.78	32.18	33.67	6.4	.8	1.7	1.9	---	56
None	2.63	3.39	10.25	16.16	10.75	.34	6.40	1.18	3.98	29.19	34.20	5.94	24.78	25.78	7.0	.7	1.2	1.5	---	108
None	13.87	17.88	10.97	17.13	8.34	.25	2.84	1.78	1.90	24.25	19.34	2.85	7.70	9.22	5.8	.6	.9	1.0	---	90

(12) Fe.(Calculated as Fe.)
Al.(" " Al.)
No.(" " No.)
Mn.(" " Mn.)
Ti.(" " TiO_2)
Ca.(" " CaO)
Mg.(" " MgO)
Si.(" " SiO_2)
Alkalimeter loss as CO_2
Alkanity as Na_2O
All samples dried at 105°C before analyzing.

Mn.x 1.3886 = Mn_3O_4
Fe.x 1.2900 = FeO

Water Glass
41.1° Baume'
Na_2O = 8.8%
SiO_2 = 28.5% 1:3.22
H_2O = Balance

When dried at 200°F the residual moisture equals approx. 6.0%.

(13) Samples dried at 200°F - 3 hrs. They were then allowed to stand in room atmosphere. Room temperature varied from 80° to 85°F. Highest humidity reading = 4.1 grains H_2O per cu. ft.

(14) Immersed in water at room temperature and then tested for firmness of adhesion and solidity with a pinching twist of the thumb and forefinger.

Cont

SLAG PROPERTIES (15)

Flux on 1 Rod	Slag from 1 Rod	Slag per Gram Flux	Slag Density	Slag Fluidity	Slag Color	Percent Composition							% Chemical Composition (19)						Physical Properties (Ver				
						SiO_2	FeO	Al_2O_3	TiO_2	CaO	MgO	MnO	C.	Mn.	P.	S.	Si.	Ti.	Welder	Aging Period	T.S. psi	Y.P. psi	Elong. in 4" %	R.A. %
Gr.	Gr.	Gr.	--	(18) Ins.	(17)														(21)	(22)				
3.46	5.94	1.72	3.149	.024	Glassy Blue ---- Shiny Black	(Base to Acid Ratio = 2.6)[18] 30.39	30.38	.02	15.23	.09	8.24	15.28	.10	.56	.01	.03	.20	.01	A	None None	72,000 72,220	61,000 61,220	16.0 12.0	28.2 17.6
																			B	None 96	67,125 67,720	60,000 59,000	10.0 15.0	17.4 24.4
3.36	5.90	1.76	3.182	.028	Glassy Purple ---- Dull Black	(Base to Acid Ratio = 2.1) 32.23	32.00	.05	14.73	.09	11.27	8.65	.10	.52	.01	.03	.19	.01	A	None None	68,220 74,000	58,720 61,720	10.5 14.5	17.4 26.6
																			B	None 48	67,500 67,720	60,000 59,720	11.0 11.8	21.3 23.7
5.62	7.58	1.30	3.266	.026	Glassy Blue ---- Dull Purple	(Base to Acid Ratio = 2.1) 32.01	26.64	.05	23.45	.32	2.69	12.48	.17	.56	.01	.03	.25	.01	A	None None	76,000 74,500	62,500 62,250	12.0 10.5	17.0 19.6
																			B	None 50	75,000 76,000	63,000 63,720	15.0 17.0	22.0 28.2
5.73	8.04	1.81	3.259	.030	Dull & Glassy Blue ---- Dark Gray	(Base to Acid Ratio = 2.8) 28.19	31.67	.03	24.09	.16	3.50	12.46	.15	.48	.01	.03	.24	.01	A	None None	74,000 73,500	60,500 58,500	11.0 10.5	20.6 20.6
																			B	None 48	75,000 74,250	62,000 62,720	18.0 21.0	23.0 42.3
5.80	8.73	1.51	3.247	.068	Dark Glassy Blue ---- Purple	(Base to Acid Ratio = 2.0) 31.99	40.69	1.04	9.17	.07	.09	16.29	.10	.38	.02	.03	.17	.01	A	None None	72,625 72,500	61,000 60,000	21.8 16.0	29.6 28.6
																			B	None 50	71,220 70,500	58,250 57,250	26.0 24.0	51.1 55.1
3.62	4.50	1.24	3.109	.025	Gray ---- Gray	(Base to Acid Ratio = 3.3) 17.00	36.30	6.28	30.12	.11	1.46	8.32	.10	.36	.01	.03	.20	.01	A	None None	72,220 70,500	59,220 59,500	11.0 9.5	25.1 18.1
																			B	None 48	67,500 67,750	57,220 57,220	13.0 14.0	25.6 27.1
4.13	5.11	1.23	3.264	.025	Dull Brown-Black ---- Dull Brown-Black	(Base to Acid Ratio = 14.2) 6.42	42.01	.03	27.22	.06	3.02	20.25	.10	.46	.02	.03	.16	.01	A	None None	72,500 68,500	59,220 58,500	17.0 13.0	30. 26.
																			B	None 50	70,000 69,000	60,220 57,500	18.5 16.5	27. 30.
3.83	4.98	1.30	3.355	.032	Very Dull Gray ---- Dull Gray	(Base to Acid Ratio = 3.4) 20.34	33.18	2.08	31.82	.01	.10	11.22	.14	.39	.01	.03	.26	.03	A	None None	74,000 75,000	62,000 62,000	15.0 13.5	24. 26.
																			B	None 52	73,500 72,500	60,720 60,000	18.0 12.0	30. 22.
2.77	3.38	1.19	3.205	.020	Glassy Blue ---- Shiny Black	(Base to Acid Ratio = 2.9) 25.10	38.87	.07	16.48	.02	2.80	15.86	.08	.42	.01	.03	.17	.01	A	None None	69,000 70,500	58,720 60,000	14.0 14.5	22. 29.
																			B	None 48	70,125 67,720	60,220 57,720	11.0 12.5	26. 21.
7.71	8.93	1.08	3.049	.078	Glassy Blue ---- Green-Yellow	(Base to Acid Ratio = 1.3) 40.29	42.18	2.18	.40	.02	.10	13.40	.09	.61	.02	.03	.22	.01	A	None None	65,000 66,750	52,500 54,000	12.5 14.0	26. 30.
																			B	None 48	66,750 66,500	54,000 54,000	22.0 25.0	36. 44.

(15) All values are on metal in t
ly deposited in a vertically upwa
(21) Welder "A" rated by qualifie
average; welder "B" rated as being
(22) Aging was done at room tempe
ported is that which elapsed from
specimen.
(23) Tensile specimen: standard .
Point obtained with dividers.
(24) Bird-eyes counted in fractur
(25) Izod specimen: standard 10mm
Values are the average of 2 readi
the other.
(26) Specific Gravity specimen: s

(18) Electrical conditions are those as used by welder "A" in making the deposit tests.

(16) Slag fluidity was determined by measuring the transverse thickness of several representative pieces of each slag.

(17) Color above broken line is that of the blebby (gas cavity) portion; that below the line is that of the metal-slag interface (contact) portion. Slag from specimen 5 is nearly all blebby; that of specimen 8 being the opposite, i.e., it is flatter and has a large contact area; specimens 1 and 4 consit of about 50:50 of each.

(18) Calculated thusly: $\frac{FeO + MnO + CaO + MgO + TiO2}{SiO_2 + Al_2O_3}$

(19) Drillings taken from grip ends of tensile specimens made by welder "B".

DEPOSIT ANALYSES.

Properties (Vertical Position)(29)							Percent of Weld Recrystallized (27)
	Elong. in 2" %	R.A. %	Bird Brss No. (24)	Izod Impact Pass Ft.Lbs. (25)	Izod Impact Rock Ft.Lbs.	Sp.Gr. --- (28)	
000	15.0	28.2	4				
250	12.0	17.8	9	68.5	55.5	7.813	80
000	10.0	17.4	9				
000	13.0	24.4	15	69.0	60.5	7.815	85
780	10.5	17.4	12				
780	14.5	26.8	11	55.5	55.5	7.805	85
000	11.0	21.3	12				
780	11.5	23.7	9	47.0	47.0	7.816	80
800	12.0	17.0	8				
250	10.5	19.8	7	54.0	51.5	7.823	85
000	15.0	22.0	8				
780	17.0	28.5	6	60.0	51.0	7.830	80
800	11.0	20.6	4				
800	10.5	20.6	2	58.5	49.0	7.814	75
000	15.0	23.0	2				
750	21.0	48.5	1	49.5	49.5	7.840	70
000	21.5	29.5	0				
000	16.0	28.8	3	45.5	44.5	7.807	70
250	26.0	51.1	0				
250	24.0	55.5	0	52.0	55.0	7.832	45
250	11.0	25.1	2				
800	9.5	18.5	7	48.0	48.0	7.806	45
250	15.0	25.9	13				
250	14.0	27.2	7	53.0	48.0	7.815	45
250	17.0	30.2	6				
800	13.0	28.5	10	41.5	46.0	7.796	75
250	18.5	27.8	13				
800	16.5	30.8	7	57.0	46.5	7.821	40
000	15.0	24.8	6				
000	15.5	26.5	5	48.5	38.5	7.807	60
750	18.0	30.5	2				
000	18.0	25.1	3	58.5	40.0	7.819	47
750	14.0	22.7	15				
000	14.5	29.2	12	61.0	46.0	7.809	45
250	11.0	26.5	14				
750	12.5	21.0	12	51.0	50.5	7.820	75
200	12.5	26.2	2				
000	14.0	30.5	0	45.5	54.0	7.760	60
000	22.0	55.2	0				
500	25.0	44.6	0	52.0	56.5	7.835	80

on metal in the "as-welded" condition, manual-
rtically upward position.
od by qualification tests as being better than
rated as being A1.
at room temperature (75-80°F). The time re-
h elapsed from machining to the testing of the

m: standard .505 x 2" gage length. Yield
dividers.
ted in fracture of tensile specimen.
standard 10mm sq.x 2mm 45° V notch x .01"R.
rage of 8 readings, each at right angles to

ity specimen: a solid cylinder .625"dia.x 1-1/2".

ISTS OF 5/32" COVERED ELECTRODES - PART II

MICROSTRUCTURE AND PHYSICAL PROPERTIES

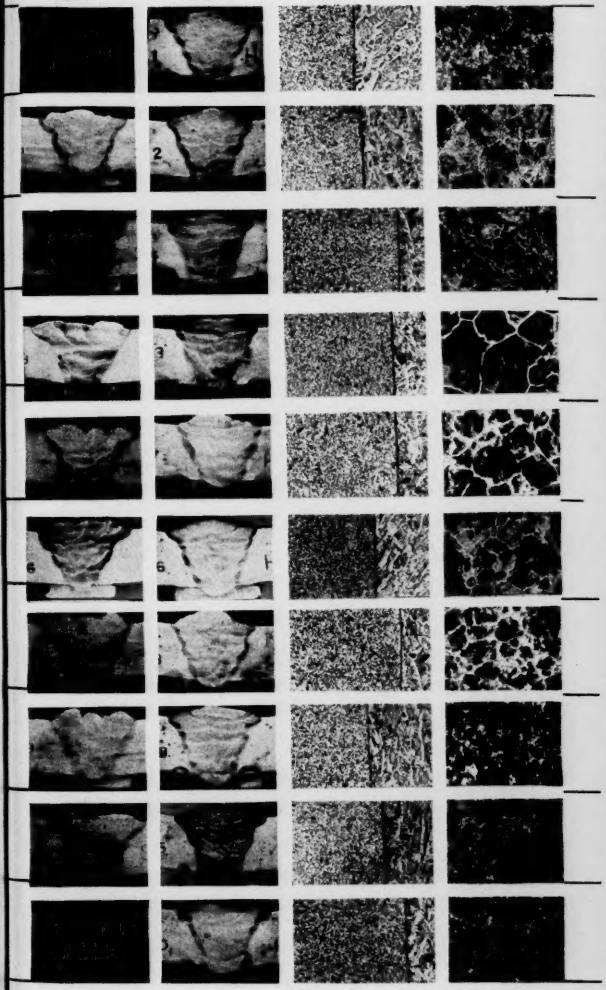
Macrostructure of Weld (28)

Made by Welder "A"

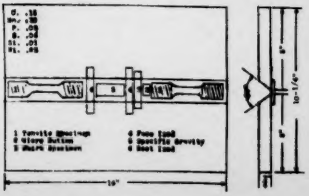
Made by Welder "B"

Microstructure of Weld Made by Welder "A"(29)

McQuaid-Ehn Test on Weld Made by Welder "B"(30)



(27) Estimated from a macro-etched .505"dia. button made from the grip end of tensile specimens.
(28) Location of macro, and all other specimens, is shown in sketch hereon.
(29) Each photomicrograph shows the percent of raw or "as-welded" metal and the amount of refined or annealed metal in the cross section of a .505" dia. tensile specimen.



Arc Current Amps.	Arc Voltage Volts	No. of Passes	Weight of Metal Deposited Lbs-Ozs		Arc Travel Ins/Min.	Electrode Consumption Ins/Min	Rate of Deposition Ozs/Hr. (33)	Deposition Efficiency % (34)	Merit Performance (35)
137	24.0	10	2	4.4	3.5	10.4	45.05	77.60	378.0
126	23.2	13	2	6.8	3.5	9.5	45.04	83.64	398.9
128	24.0	11	2	3.4	3.6	9.4	43.85	81.32	312.1
126	25.0	13	2	7.3	3.9	10.6	46.96	80.30	397.0
129	27.0	11	2	0.3	3.1	9.5	34.03	59.90	169.7
105	29.0	13	2	6.6	3.2	8.1	38.48	74.98	319.2
130	26.6	10	2	2.1	3.8	11.7	41.40	60.00	301.9
107	26.0	13	2	6.1	3.1	8.1	38.48	74.13	385.2
139	27.0	12	2	1.1	3.4	9.9	38.69	59.05	222.1
106	28.0	10	2	7.0	2.4	6.1	38.17	70.89	439.6
148	23.0	11	2	9.1	3.4	10.0	46.08	77.80	397.8
118	23.7	13	2	12.3	3.1	8.5	38.97	83.88	398.4
148	22.7	10	2	7.4	4.1	13.4	39.78	77.83	478.8
109	22.9	13	2	11.6	3.6	9.0	44.88	83.39	398.7
152	25.8	11	2	8.3	3.6	12.1	46.23	67.60	340.8
122	25.1	13	2	10.8	3.1	9.5	37.39	74.08	311.4
148	23.8	11	2	5.8	3.8	10.9	48.18	79.15	388.7
138	23.8	13	2	7.3	3.9	10.1	44.88	81.84	390.1
142	24.0	11	2	5.5	3.1	9.2	40.08	68.48	251.1
130	24.4	7	2	6.1	2.2	6.9	39.48	89.98	324.0

(30) The foregoing structures are not truly representative. considerably within each specimen. The structure which was dominant was photographed.

(31) Welding was done vertically upward using the horizontal procedure. All plates were preheated to 200°F before weldin the laying down of each layer, the assembly was allowed to c room temperature 5 mins. followed by cooling with boiling wa 9-10 mins. Interpass temperature at no time was under 200°F

(33) Increase in weight of plate divided by net time, and ex in ounces per hour.

(34) Ratio of the increase in weight of plate to the weight consumed. Spec.2297.4/10/36, calls for minimum D.E. of 60%.

(36) $\frac{I.E.x\ Elong.\ x\ D.E.x\ P.S.}{10,000,000}$ (36) $4(T.S./10,000)+Elong.$

(37) $(\frac{I.E.x\ Elong.}{10,000})+(\%\ Bends\ Passed\ by\ Welders\ 2\text{-}6\text{-}P\ x\ 2)+$

Satisfactory Un. and Dem.+ % Appearance of Bead], [Manual C

Coat Rating].

Deposition Efficiency % (54)	Merit Factor or Performance Value (1) (55)	(2) (56)	(3) (57)	Welder	Seams in Weld Metal (58)	Pinholes in Macro Section	Depth of H.A. Zone Inches (59)	% Wgt. Loss in Hot HCl (20:80, 48°) (60)	Bare vs Coated Vertical Beads (Rev. Polarity) Bare E	Bare I	Coated E	Coated I	Wattage (61) Watts Consumed by Coat
77.40	378.0	388.8	382.9	A	- - -	2	3/32-1/8	----	19-124 (2356)		24-110 (2640)		384
83.84	388.9	394.4	382.1	B	R-L-F	1	3/32-1/8	4.88					
81.90	312.1	292.6	282.9	A	- - -	3	3/32	----	20-120 (2400)		24-116 (2784)		384
80.30	287.0	280.8	311.1	B	R-L-S	4	3/32	3.98					
89.90	168.7	241.8	228.4	A	- - -	3	3/32-1/8	----	19-128 (2432)		26-112 (2912)		480
94.88	319.2	287.3	266.2	B	R-S-F	1	3/32-1/8	3.85					
80.00	301.9	270.7	321.4	A	- - -	1	-3/32	----	20-126 (2520)		27-100 (2700)		180
74.13	283.8	275.1	276.8	B	R-S-F	1	3/32-1/8	4.64					
89.88	292.1	278.2	245.4	A	- - -	1	3/32	----	19-124 (2356)		27-102 (2754)		396
70.89	439.6	300.3	288.3	B	R-L-F	3	1/16-3/32	4.17					
77.80	287.6	286.1	294.7	A	- - -	1	3/32-1/8	----	19-124 (2356)		23.5-117 (2730)		384
83.88	298.4	288.8	318.5	B	R-L-F	2	1/8	3.93					
77.88	476.5	287.7	308.8	A	- - -	0	1/8	----	19-130 (2340)		23-122 (2806)		486
83.39	288.7	290.0	288.6	B	R-L-M	4	3/32	3.83					
87.02	248.8	285.9	263.9	A	- - -	8	3/32-1/8	----	19-127 (2413)		24.5-107 (2622)		320
74.02	311.4	270.8	288.4	B	R-S-F	0	3/32-1/8	3.88					
79.18	288.7	287.7	318.8	A	- - -	1	3/32	----	19-120 (2470)		24-116 (2784)		314
81.94	280.1	288.8	288.8	B	R-L-F	6	3/32	4.80					
88.42	251.1	270.4	178.3	A	- - -	8	1/8	----	19-128 (2432)		24-114 (2736)		304
89.88	284.0	284.8	273.3	B	R-L-F	2	3/32-1/8	3.88					

presentative. They vary
ure which was most pre-

the horizontal layer
" before welding. After
n allowed to stand at
ith boiling water for
as under 20Omm.
t time, and expressed

to the weight of electrodes
e D.E. of dep.
10,000 x Elong. + D.E. + Ab.Gr.).

s B-S-F x 8) + (% 45°Fillets

h) + (Manual Current Range x

100

distribution
(58) R = Random; L = Large; M = Medium; S = Small; F = Few; N = Numerous
(59) H.A. = Heat Affected.
(60) Object of Test: To discover nitrogen-rich areas. Dark areas contain over .040% nitrogen; light areas, less than .040%. Reference: A.J. Moses, The Am.Welding Soc. Journal, April 1938.
(61) Welds made with constant energy set. E = Arc Volts; I = Amperes.

(a) 1030 Btu/lb.to boiling.
(b) Latent Heat of Vaporization of iron = 2920 Btu/lb.

FIELD TESTS

Welders' Qualification Bend Test (42)						High Current Manually Made Vertical Root Bend Tests		Low Current (A5) Manually made Vertical Root Bend Tests		45° And 90° Vertical Fillet Welds(46)						
Welder B (43) (Very Good)		Welder S (Good)		Welder P (Poor)		#1	#2	#1	#2	Angle of Vertical Fillet	Direction of Welding	Arc Voltage	Arc Current	Burning Through	Desinnification	Appearance
Face	Root	Face	Root	Face	Root	Root	Root	Root	Root	(47)		Volts	Amps.		(48)	(49)
	(44)															
(129-23-61)		(138-24-71)		(130-25-64)		150 amps.		90 amps.								
OK	OK	NG 150°	OK	NG 150°	OK	OK	OK	OK	OK	45°-B	Up	27	102	None	80%	70%
										45°-B	Down	27	120	None	20%	80%
										90°-J	Up	25	133			
										90°-J	Down	25	145			
(125-23-61)		(130-23-68)		(133-25-68)		155 amps.		95 amps.								
OK	OK	NG 150°	OK	OK	NG 150°	OK	OK	OK	NG 150°	45°-B	Up	27	102	None	70%	60%
										45°-B	Down	27	120	None	30%	80%
										90°-J	Up	24	115			
										90°-J	Down	25	132			
(110-24-48)		(110-26-50)		(115-23-60)		150 amps.		95 amps.								
NG 150°	OK	NG 150°	NG 110°	NG 150°	NG 30°	OK	OK	OK	OK	45°-B	Up	27	85	None	65%	80%
										45°-B	Down	26	102	None	25%	90%
										90°-J	Up	27	110			
										90°-J	Down	26	127			
(123-25-61)		(118-28-58)		(120-27-62)		150 amps.		95 amps.								
OK	OK	OK	NG 150°	OK	NG 47°	OK	NG 150°	OK	NG	45°-B	Up	27	85	None	70%	80%
										45°-B	Down	27	100	None	25%	80%
										90°-J	Up	26	102			
										90°-J	Down	26	132			
(115-25-50)		(110-25-51)		(120-26-52)		150 amps.		100 amps.								
OK	OK	NG 150°	NG 150°	NG 150°	NG 24°	OK	NG	OK	NG 150°	45°-B	Up	25	102	Yes	80%	80%
										45°-B	Down	27	120	Yes	80%	40%
										90°-J	Up	27	112			
										90°-J	Down	27	133			
(125-23-61)		(110-24-52)		(130-24-66)		170 amps.		100 amps.								
OK	OK	NG 150°	OK	OK	NG 53°	OK	OK	OK	OK	45°-B	Up	24	105	Yes	80%	80%
										45°-B	Down	24	125	None	30%	90%
										90°-J	Up	24	120			
										90°-J	Down	25	140			
(138-24-68)		(130-23-66)		(120-24-64)		160 amps.		115 amps.								
OK	OK	NG 150°	OK	NG 150°	NG 150°	OK	NG 48°	OK	OK	45°-B	Up	25	120	None	75%	65%
										45°-B	Down	24	136	None	35%	100%
										90°-J	Up	25	127			
										90°-J	Down	25	143			
(127-21-61)		(130-24-58)		(125-27-56)		160 amps.		100 amps.								
NG 150°	NG 150°	NG 150°	OK	NG 150°	NG 25°	NG	NG	NG	NG 150°	45°-B	Up	24	105	None	65%	90%
										45°-B	Down	25	120	None	25%	80%
										90°-J	Up	24	118			
										90°-J	Down	24	128			
(140-23-61)		(135-25-50)		(145-25-64)		170 amps.		100 amps.								
OK	OK	NG 150°	OK	NG 150°	OK	OK	NG	NG	NG	45°-B	Up	25	125	Yes	65%	80%
										45°-B	Down	24	140	None	40%	85%
										90°-J	Up	25	125			
										90°-J	Down	23	145			
(120-23-50)		(125-25-58)		(130-23-52)		130 amps.		110 amps.								
NG 150°	OK	OK	NG 150°	NG 80°	NG 39°	NG	NG	NG	NG	45°-B	Up	25	107	Yes	65%	50%
										45°-B	Down	26	130	Yes	65%	5%
										90°-J	Up	25	124			
										90°-J	Down	26	140			

(A2) Made in accordance with General Specifications for Inspection of Material, Appendix VII-Welding, Part E, Section E-1. Sketch hereon.
(A3) Welder "B" A-1; welder "S", an average good worker; welder "P" is fair, i.e., less than average skill.
(A4) Figures in parentheses are: amperes, arc volts, and machine setting. Machine: Hobart Arc Welder Simplified, 400-Ampere, Single Operator with Cutler Hammer Generator set 60 cycle, 208V, 4720RPM. 220V-2HP motor. Welding was vertically upward with 1/16" root opening.
(A5) Tests done at Annapolis to determine current range.

(A6) Fillets laid in angled formed by one galvanized and one black medium steel (M) plate, each 3/16" thick by 4" wide by 14" high. Length of each fillet - 4 to 6 inches.
(A7) 45-degree fillet welds made by welder "B"; 90-degree fillets, by welder "J".
(A8) Expressed as percent reduction in thickness of galvanizing on reverse side of plate, directly in way of fillet. Values are approximate.
(A9) Percent of 4-inch length of bead which resembled that shown in "Appearance Standards For Fillet Welds", Spec. 2297.

OSCILLOGRAM AND ARCHOSCOPE STUDIES

Position-ification (48)	Appear-ance (49)	Data Derived From Oscillograms(50)												Arc Stability Tests								
		Maximum Current				Optimum Current				Minimum Current				Short Circuit Periods				Arcoscogram Arc Stability			Automatic(52) Bead Opacity		
		A	B	C	D	A	B	C	D	A	B	C	D	Max. I	Opt. I	Min. I	Ave. I (51)	Max. I	Opt. I	Min. I	Max. I	Opt. I	Min. I
80% 20%	70% 80%	8	1/600	(120-28) 1/80	1/120	5	1/160	1/80	1/80	12	1/600	(95-28) 1/120	1/80	6.0	6.0	6.5	6.2	F	G	E	F	G	G
70% 30%	60% 80%	16	1/600	(130-27) 1/80	1/120	12	1/600	1/40	1/600-1/40 4:1	7	1/600	(80-27) 1/80	1/80	12.5	5.6	9.5	8.2	E	S	F-E	I	G-F	F
65% 35%	60% 90%	2:1 0-16	1/600	(120-28) 1/80	1/120	3	1/300	1/80	1/300-1/80	24	1/600	(100-28) 1/100	1/120	9.5	6.9	20.0	12.1	E	F	E	G	F	F
70% 30%	60% 80%	6	1/600	(120-28) 1/80	1/120	14	1/600	1/80	1/120	5	1/600	(80-28) 1/120	1/120	5.0	12.0	4.0	7.0	G	F	E	G-F	F	G
80% 20%	90% 40%	2	1/600	(110-27) 1/100	1/100	16	1/600	1/80	1/120	12	1/300	(90-26) 1/40	1/120	2.0	27.0	10.0	13.0	E	G	E	I	F	I
80% 30%	90% 90%	1	1/600	(140-28) 1/80	---	12	1/600	1/80	1/80	12	1/120	(100-26) 1/40	1/80	1.5	15.0	15.0	10.5	F	G	G	I	I	G
75% 35%	65% 100%	4	1/80	(130-24) 1/80	1/80	16	1/120	1/80	1/80	2	1/600	(100-24) 1/80	1/80	7.0	20.0	3.0	10.0	-	G-E	G-E	I	I	F
65% 28%	90% 90%	14	1/600	(118-24) 1/80	1/400	12	1/600	1/120	1/120	12	1/600	(106-26) 1/300	1/300	9.0	10.0	4.0	5.5	F	G-E	S	I	G	G
65% 40%	80% 85%	9	1/600	(130-26) 1/40	1/80	8	1/600	1/80	1/80	11	1/480	(90-80) 1/80	1/120	12.0	10.0	8.0	10.0	F-E	F-E	G	I	I	F
85% 65%	80% 85%	6	1/240	(100-27) 1/80	1/240	22	1/300	1/100	1/120	10	1/600	(85-27) 1/80	1/120	5.0	18.0	1.0	7.1	F	F-E	E	F	I	I

(50) Oscillographic data on subject electrodes was obtained by the Engineering Experiment Station, Annapolis, Md. Tests were made using an automatic welding head and welding vertically upwards.

A - Short circuit frequency per second.
B - Minimum short circuit period in seconds
C - Maximum short circuit period in seconds.
D - Average duration of short circuit periods in seconds.

Figures in parenthesis are current and voltage values in amperes and volts.

(51) Short circuit periods per electrode, time elapsed per electrode, % of total time.
(52) Beads welded vertically upwards, and graded as to appearance only. Above data was obtained from E.E.S Report No. B-488, Feb. 16, 1939. The current values used in the test are given elsewhere in these tables.

G: Good
F: Fair
S: Sluggish
E: Erratic
I: Irregular
C: Coarse

.01 per cent, and that FeO, Fe_3O_4, CaO, and MnO are strong arc stabilizers. The arcronograms, however, did not discover the existence of any such relationship.

Summary.

(1) The history of the progress of electrode technology has been one of increasingly higher realization of ductility through elimination of deleterious gases. Bare wire welding had realized approximately one-sixth of the potential ductility inherently resident in weld metal; cellulose-covered electrodes, by a drastic reduction of oxygen and nitrogen in the deposit, have wrested one-third to one-half of the inherent value. It appears that the next probable advance in this direction will be an all-position electrode emitting an irreducible minimum of hydrogen.

ACKNOWLEDGMENT.

The writer wishes to express his appreciation for helpful suggestions and assistance in recording and preparing much of the experimental data to Mr. P. C. Greene, Welding Engineer at the Yard; and to Messrs. R. S. Gibbs and J. R. Andrews, chemists, for the chemical analyses.

STOPPING AND BACKING TRIALS OF A DESTROYER.

By Lieutenant Commander Pleasant D. Gold, Jr.,
U. S. Navy, Member.

Stopping and backing of ships is a matter of concern to designers, particularly for vessels to be propelled by Diesel engines or electric motors. The author here makes a valuable addition to the available stock of data on the subject.

Recorded data of the shaft torque during the transient state of stopping and backing of high-speed vessels are scarce. Estimates of torque during reversal are, for naval vessels, based upon trials and model tests of a limited number of ships. The torque and thrust curves, published in the August issue, 1938, of this Journal, (a), by Rear Admiral S. M. Robinson, are now used. A deceleration is estimated to determine the velocities, when entering these curves. The results obtained from these curves are pessimistic, thus affording an adequate factor of safety. For the high-speed turbine drive ship the astern turbines required for backing are sufficient also for stopping, therefore, the problem is of academic interest only. For Diesel or electric type drives such is not the case, and special means must be provided for stopping, or stopping and reversing the shaft.

At the request of one of the design agencies of the new construction program, tests were conducted on the U. S. S. *Roe*, DD418, at Rockland, Maine, on 26 and 27 August, 1940. Inasmuch as approximately one month was allowed for preparations for these trials, it was necessary to utilize apparatus and procedures readily available. Unfortunately no reliable thrustmeter capable of recording instantaneous thrust during the transient state was available, consequently no record of thrust was obtained. Two torsionmeters were used on each shaft and the general agreement between these

meters gave evidence of their reliability. Two methods of obtaining instantaneous revolutions were provided and were in entire agreement. Only one method was used for obtaining the instantaneous position of the ship. However, that method had been successfully employed a number of times in the past for turning trials and the technique had been thoroughly developed. No instantaneous velocities were obtained, therefore, it was necessary to calculate these by differentiation of the instantaneous position curve. While it is believed that the velocities so obtained are relatively accurate, it is unfortunate that no reliable means was available for obtaining directly these instantaneous velocities.

Prior to describing these trials and the technique and instrumentation involved, it is believed advantageous to consider the physical relations of the many variables. Some of these variables are capable of analysis, others of approximation, and others remain unknown.

The force and torque equations for the ship and shafts may be written:

For the ship:

$$M \frac{dV}{dt} = -R + T$$

and for the shaft

$$I \frac{d\omega}{dt} = -Q_e + Q_p \qquad \text{(neglecting friction)}$$

where M = ship's mass
V = velocity
t = time
R = effective resistance
T = effective thrust
I = moment of inertia of rotating system
ω = angular velocity
Q_e = engine (or motor) torque
Q_p = propeller torque

While these equations are not, at present, capable of solution, a knowledge of the unknowns and their trend is helpful in recognizing the extent of the problem.

In the first equation " M " is known.

" R " under steady state conditions may be obtained from model tests or calculated; however, the resistance of the ship while decelerating is probably somewhat different from the steady state resistance, inasmuch as the inertia of the boundary layer differs at any two steady state velocities. During deceleration or acceleration, this change of inertia of the boundary layer will affect the relative velocities of the ship and that layer, and hence, affect the resistance. The relative magnitude of this effect is unknown. However, Dr. G. Kempf, in his discussion of Mr. J. F. C. Conn's paper, (c), suggested that 5 per cent be added to the mass of the ship to compensate for this effect. How the boundary layer effect varies with differences in type and size of hull is likewise unknown.

" T " is unknown. The " T " of the formula equals the propeller thrust minus the thrust deduction. Thrust deduction or augmentation of resistance, is the pressure effect on the ship's hull caused by the velocities induced by the propeller. The thrust deduction factor is usually expressed as a fraction of the propeller thrust. The model tests of this ship indicate that this factor is approximately .20 while backing. The model tests were conducted at constant speed and therefore the thrust deduction so obtained is probably inaccurate for the transient conditions under consideration. In spite of this, it is believed that if this factor is assumed to be a constant percentage of the propeller thrust, no error of large magnitude will be introduced. The propeller thrust is an unknown function of the propeller torque. This function, theoretically, may be obtained from model tests conducted in variable pressure tunnels. J. F. C. Conn found, in his tests conducted in a model basin and not verified in a variable pressure tunnel, that the value of $\frac{TD}{Q}$ (where D equals propeller diameter) amounts to approximately 8 when the propellers are turning in the ahead direction and 5.5 when turning in the astern direction. Mr. W. G. A. Perring, (c), attributed the difference between ahead and astern values to the change in virtual pitch of the blade.

In considering the second formula, " I " may be calculated with fair accuracy.

"Q_e" may be obtained from turbine tests, analyses of steam and blade speeds, or from motor or engine tests. "Q_e" may then be expressed approximately as a function of "ω."

"Q_p" or propeller torque is unknown. Were it possible to express "Q_p" as a function of "ω" and "V," the equations would then be capable of approximate solution. By model tests, conducted in the Model Basin and corrected for cavitation in the variable pressure tunnel, it is theoretically possible to determine this function. Due to the limitations of the present model basin at Washington Navy Yard, and the 12-inch throat variable pressure tunnel, entirely satisfactory results have not been obtained. It is hoped that, with the new basin and the 27-inch throat variable pressure tunnel now under construction, these relationships may be accurately determined.

An interesting analysis of the flow conditions around the propeller blades was included in Mr. R. H. Tingey's discussion of Mr. W. E. Thau's paper, (d), in the 1937 Transactions of the Society of the Naval Architects and Marine Engineers. As was shown in this paper, the propeller passes through the following states:

(*a*) The first period is that from normal to zero positive slip. During this period, the propeller thrust is positive and the reaction of the water on the blades tends to decrease the propeller revolutions. The propeller torque is, therefore, of the same sign, as in the steady state ahead condition. Please refer to Figure 1-a, and

$$M \frac{dV}{dt} = -R + T$$

and

$$I \frac{d\omega}{dt} = -Q_e - Q_p$$

Inasmuch as both the astern turbine and the propeller act to decrease the revolutions, this period is passed through very rapidly.

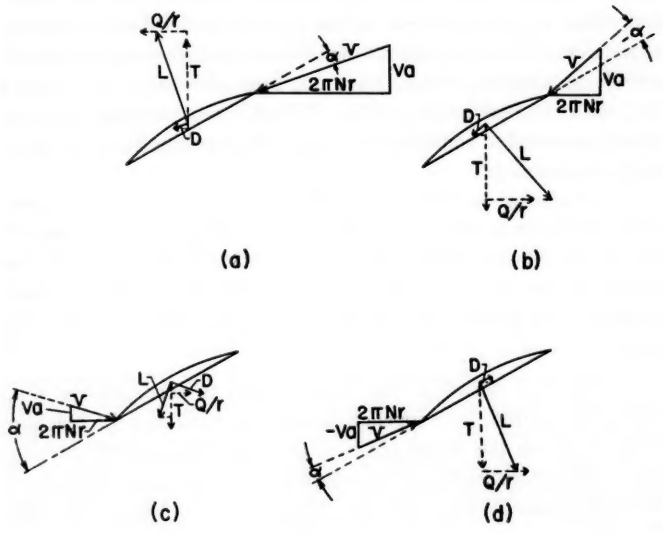
(*b*) The second period is that of negative slip. As soon as the component of the lift tending to increase the propeller revolutions exceeds the component of the drag, the reaction of the water on the

blades becomes that of a turbine and the propeller torque changes sign. Please refer to Figure 1-b, and

$$M \frac{dV}{dt} = -R - T$$

and

$$I \frac{d\omega}{dt} = -Q_e + Q_p$$



L = Lift	Va = Ships Velocity (corrected for wake)
D = Drag	v = Relative Velocity
T = Thrust	N = R.P.M.
Q = Torque	α = Slip angle or angle of attack
	r = Propeller radius

FIGURE 1.
Velocity and force diagram of the propeller for different conditions of flow.

This period continues until the shaft is stopped. At some point in this period, separation or stall occurs and the lift forces become

indeterminate. This period during the stalled state is frequently referred to as the cavitation period. Whether actual cavitation occurs or not, erratic behavior of both thrust and torque may be expected. Dr. G. Kempf, in his discussion of Mr. Conn's paper, presented the results of a model test conducted in the Hamburg tank, which test showed this erratic behavior. Inasmuch as true cavitation does not occur in model tests conducted in an open basin, the variations in torque determined on this test indicate the effect of separation or of air inducted to the propeller suction. Cavitation probably does occur, however, on full scale propellers under the "stalled" conditions. Glauert's formulae for blades in the stalled state may be used for approximate analysis, although these formulae do not account for the fluctuations in both torque and thrust known to occur.

(*c*) The third period may be considered as that occurring from the time that the shaft starts to reverse until the ship stops. This period is but a continuation of the second period inasmuch as the forces on the propeller have the same sign. Please refer to Figure 1-c, and

$$M \frac{dV}{dt} = -R - T$$

and

$$I \frac{d\omega}{dt} = -Q_e + Q_p$$

(*d*) The fourth period is that period after the ship commences backing and makes sternway. Please refer to Figure 1-d, and

$$M \frac{dV}{dt} = R - T$$

$$I \frac{d\omega}{dt} = Q_e + Q_p$$

Critical values of torque and thrust would be expected at the beginning and end of the stall or separation condition. The majority of tests show this to be true. Aerodynamic tests show

that blade shape as well as relative velocities and angle of attack play an important part in determining not only when this critical point occurs, but also its value.

It is evident that, due to the many indeterminate variables, while analysis of the limiting conditions may prove of value in estimating backing performance, at the present time full scale backing trials are necessary.

Description of the Trials.

The hull form of this vessel is normal for vessels of the class. The hull characteristics are:

Length	= 341.3 feet
Beam	= 35.9 feet
Design Draft	= 11.35 feet
Design Displacement	= 1935 tons
Trial Displacement	= 2315 tons

Propeller characteristics (two propellers):

Blade Tip Immersion	= 4.3 feet
Number of Blades	= 3
Diameter	= 11.25 feet
Pitch	= 12.5
Mean Width Ratio	= .48
Blade Thickness Fraction	= .063
Rotation	= outward (ahead)

The torque characteristics of the turbine are shown in Figure 2. These curves were copied from similar curves furnished by the manufacturer.

The trials were conducted at Rockland, Maine, since the Experimental Model Basin had previously laid out a course for turning trials at that place. Two shore stations were established and manned by Model Basin personnel. The distance between these stations and the true bearing had been accurately determined. Samples of the photographs obtained are shown. The first photograph was taken from station No. 2, viewing station No. 1. This picture enables relative bearings taken from the two stations to be

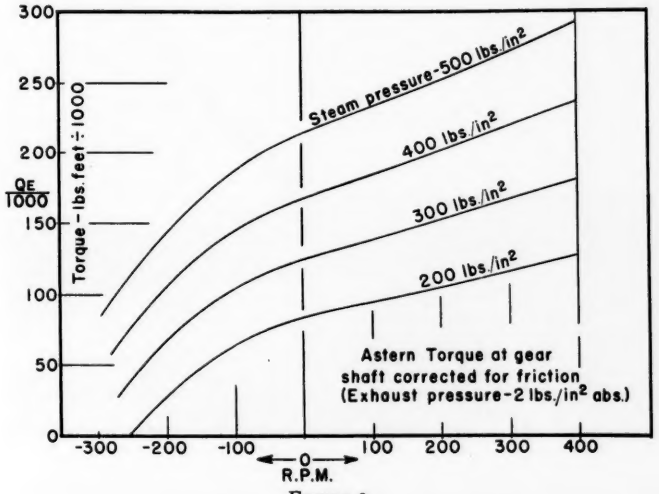


FIGURE 2.
Astern Torque at various shaft revolutions.

related. The second photograph was taken from station No. 2 of the destroyer. The third photograph shows the apparatus used at each station. The field radio set with which these stations maintained continuous communication with the ship is shown at the left of this photograph. Figure 6 shows the method for plotting the instantaneous position of the ship. At a signal from the ship by both radio and searchlight, the camera party at both stations obtained the bearing of the ships by these photographic records. The position of the ship at that instant was, therefore, accurately determined. As shown on the figure, a three-bell and light stand-by signal was given one-half minute prior to the beginning of the run; a two-bell, fifteen seconds before, and at the start of the run and every five seconds thereafter a one-bell signal was given.

Similarly, bells and lights, located at all observing stations on board ship, indicated the commencement of the run and the time intervals. The control contactor, located on the bridge, was manned by an officer from the Experimental Model Basin. He also maintained communication with the shore stations by radio.

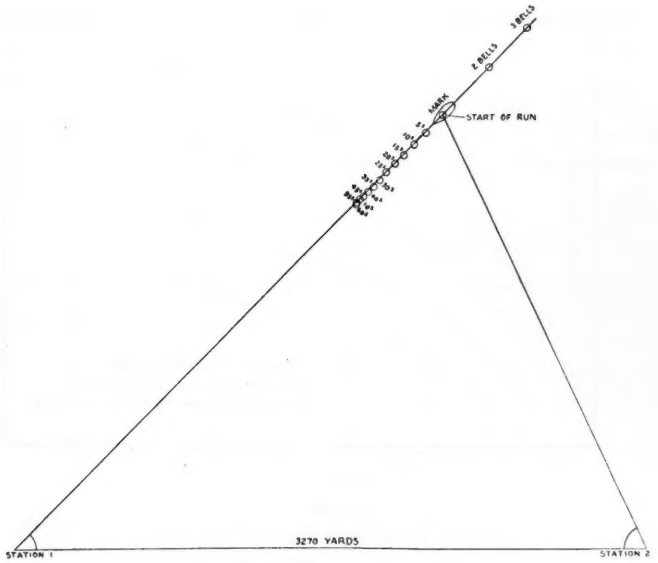


FIGURE 6.
Sample record of triangulation data.

Two torsionmeters, one for each shaft, were provided by the Naval Research Laboratory. These torsionmeters were an electric type, consisting of an electronic strain gauge mounted on the sleeve of a "Ford" type torsionmeter in place of the magnetic strain gauge normally used. This instrument was described by Gunn (e) and Hall (f). The electric circuits from the torsionmeters were led to a multi-element "Duddell" oscillograph which had an attached camera. The photograph, Figure 7, is an example of the record obtained of one run. Runs were periodically conducted to obtain the zero torque position. During the approach of each run, steady state comparisons were made between these torsionmeters and the "Ford" type meters.

Two torsionmeters, one for each shaft, of the Siemen's-McNab (Ford type) also were installed. Sixteen millimeter cameras were used to obtain a continuous record of the galvanometer dial and the meter setting. An observer attempted to hold the galvanometer

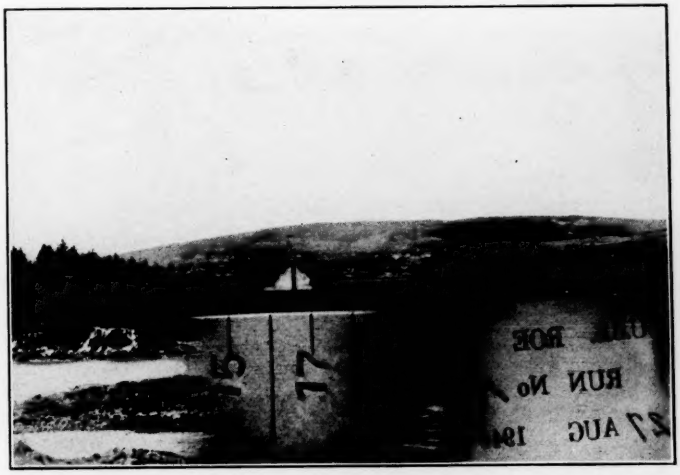


FIGURE 3.
Photographic establishment of base line for triangulation of ship's position.

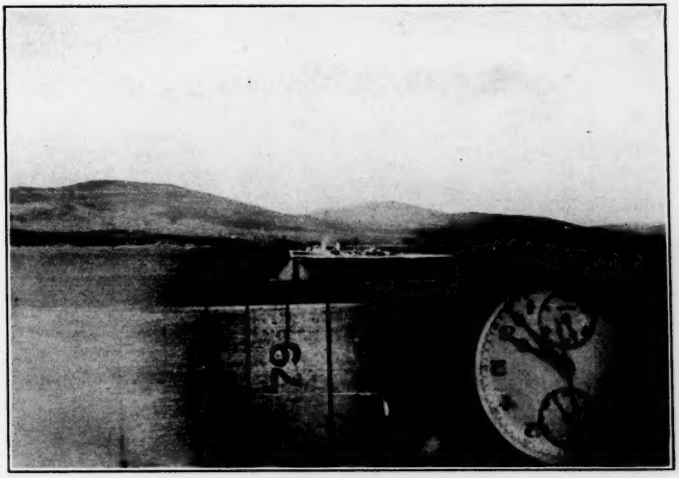


FIGURE 4.
Photographic record of ship's bearing.

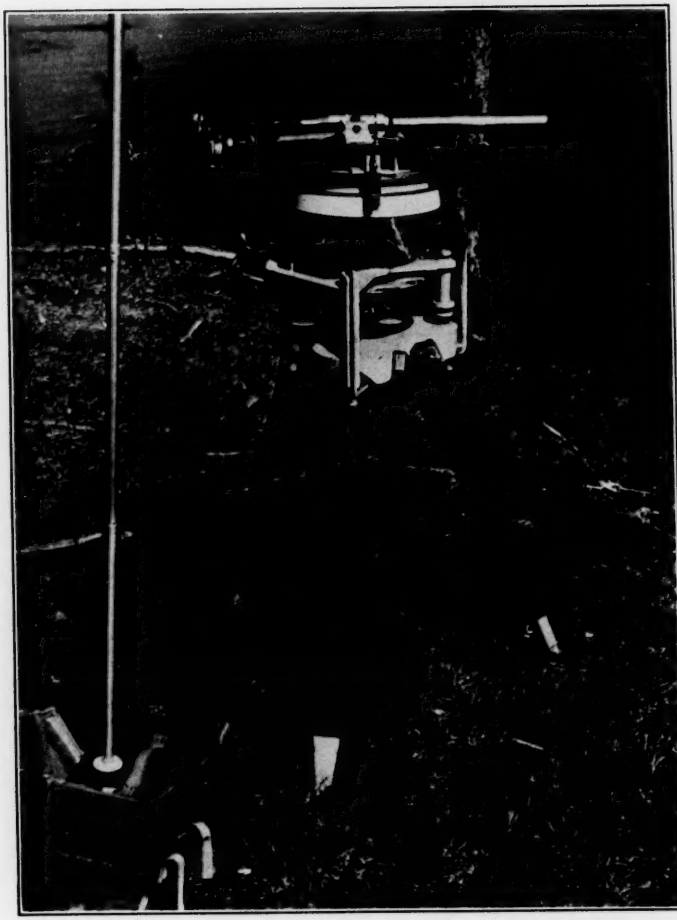


FIGURE 5.

Telescope and attachments for photographically recording ship's position from shore stations.

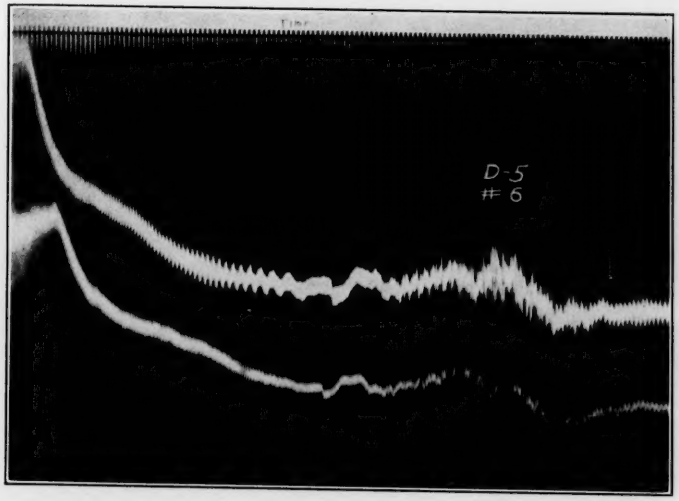


FIGURE 7.
Sample record of N. R. L. torsionmeter.

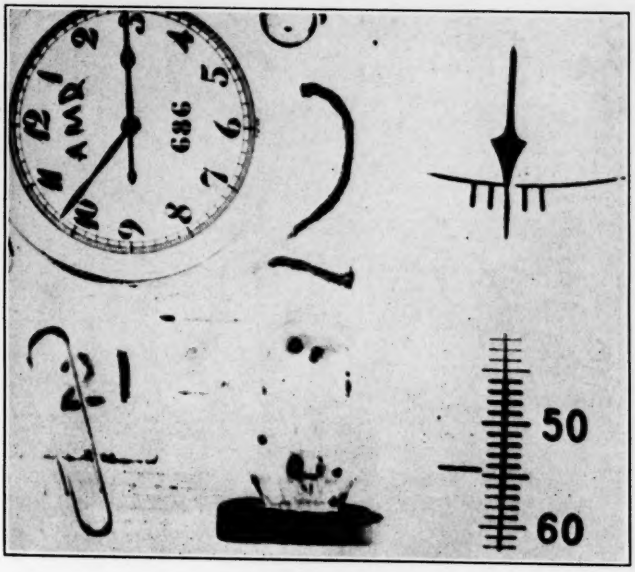


FIGURE 8.
Sample record of Ford Torsionmeter.

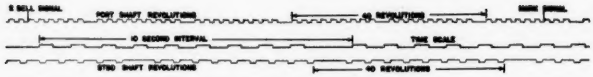


FIGURE 9.
Sample of chronometer and chronograph record.

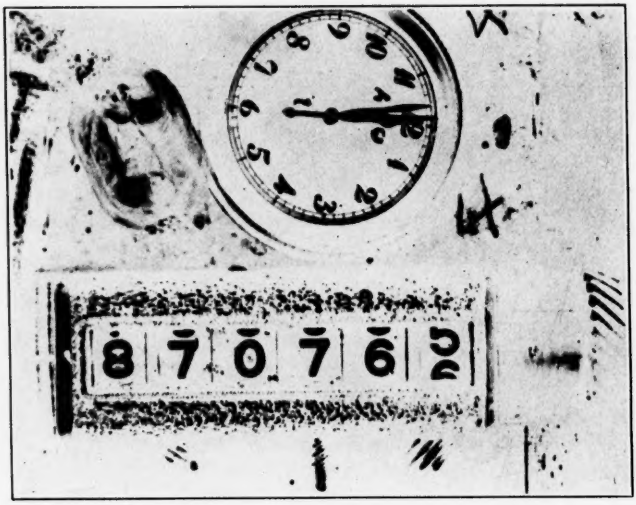


FIGURE 10.
Sample record of revolution counter.

needle on zero. Correction for off zero positions were obtained, and it was assumed that, if the galvanometer needle was momentarily stationary, the reading when corrected for the amount that the needle was off zero, was sufficiently accurate. The developed film was projected at slow speed and the dial readings obtained. Only those readings, when the galvanometer needle was stationary, were used. Lag should, therefore, have been eliminated. The photograph, Figure 8, shows one frame of the moving picture record obtained. The galvanometer needle is shown at zero in the upper right-hand corner. The meter setting is shown in the lower right-hand corner. The light in the center of the picture was in the bell circuit. This light, together with the stop watch shown, gave a continuous time record.

A chronograph was installed to obtain shaft revolutions. The sample record, Figure 9, shows the revolution scale of each shaft obtained from Experimental Model Basin counters and a time scale obtained from a chronometer attached to the chronograph. Due to the use of different gear ratios, the port and starboard scales differ.

A record of the shaft revolutions was also obtained by sixteen millimeter cameras mounted over the revolution counter. As this record checked with that obtained by the chronograph, this additional record was unnecessary. One frame taken from this film is shown in the photograph, Figure 10.

The following runs were made:

Various speeds ahead to full astern, Figures 11 to 24, inclusive.

Full speed ahead to two-thirds astern, Figure 25.

Full speed ahead to one-third astern, Figure 26.

Full speed ahead to stop (ahead throttles were closed and ship permitted to decelerate normally), Figure 27.

Twenty knots ahead to stop (normal deceleration), Figure 28.

Full speed astern to full speed ahead, Figure 29.

Two-thirds speed astern to full speed ahead, Figure 30.

One-third speed astern to full speed ahead, Figure 31.

Also three runs were made from various ahead speeds (Full, 33 knots and 25 knots) to full astern during which the ahead throttle

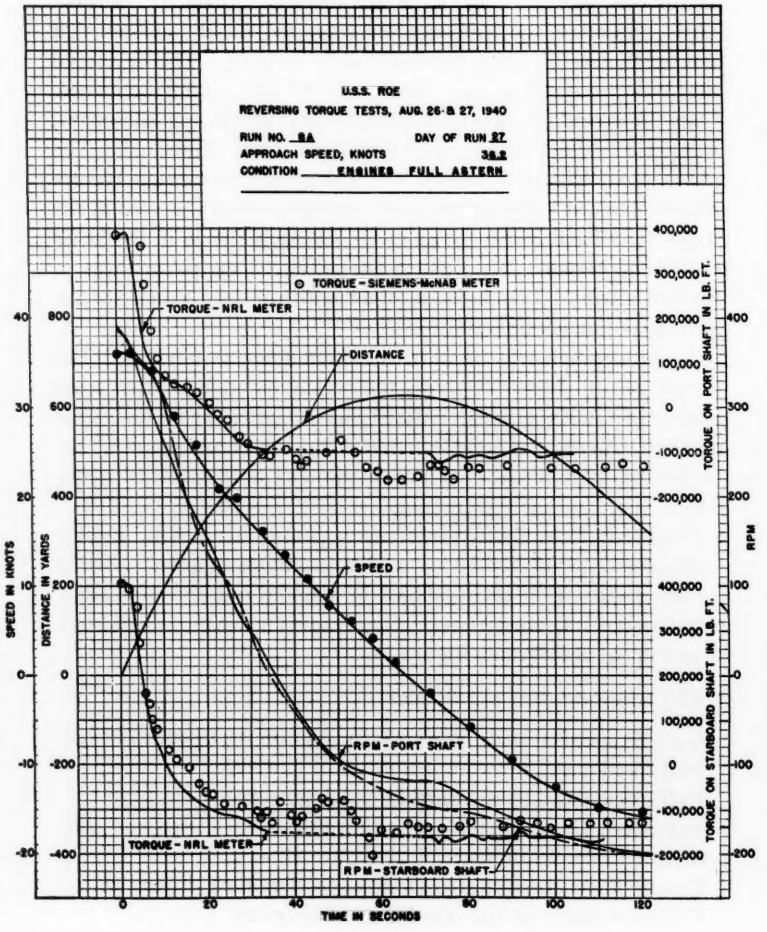


FIGURE 11.
Record of crash astern run from 36.2 knots.

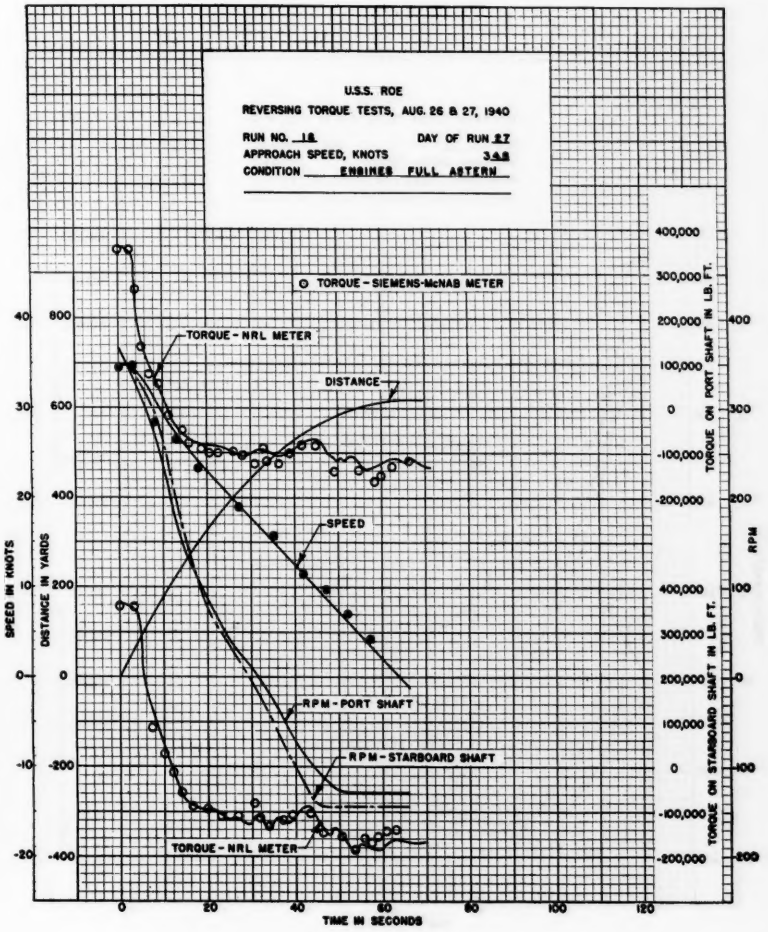

U.S.S. ROE
REVERSING TORQUE TESTS, AUG. 26 & 27, 1940
RUN NO. 18 DAY OF RUN 27
APPROACH SPEED, KNOTS 34.8
CONDITION ENGINES FULL ASTERN
O TORQUE - SIEMENS-McNAB METER
TORQUE - NRL METER
DISTANCE
SPEED
RPM - PORT SHAFT
RPM - STARBOARD SHAFT
TORQUE - NRL METER
SPEED IN KNOTS
DISTANCE IN YARDS
TORQUE ON PORT SHAFT IN LB. FT.
TORQUE ON STARBOARD SHAFT IN LB. FT.
RPM
TIME IN SECONDS

FIGURE 12.
Record of crash astern run from 34.8 knots.

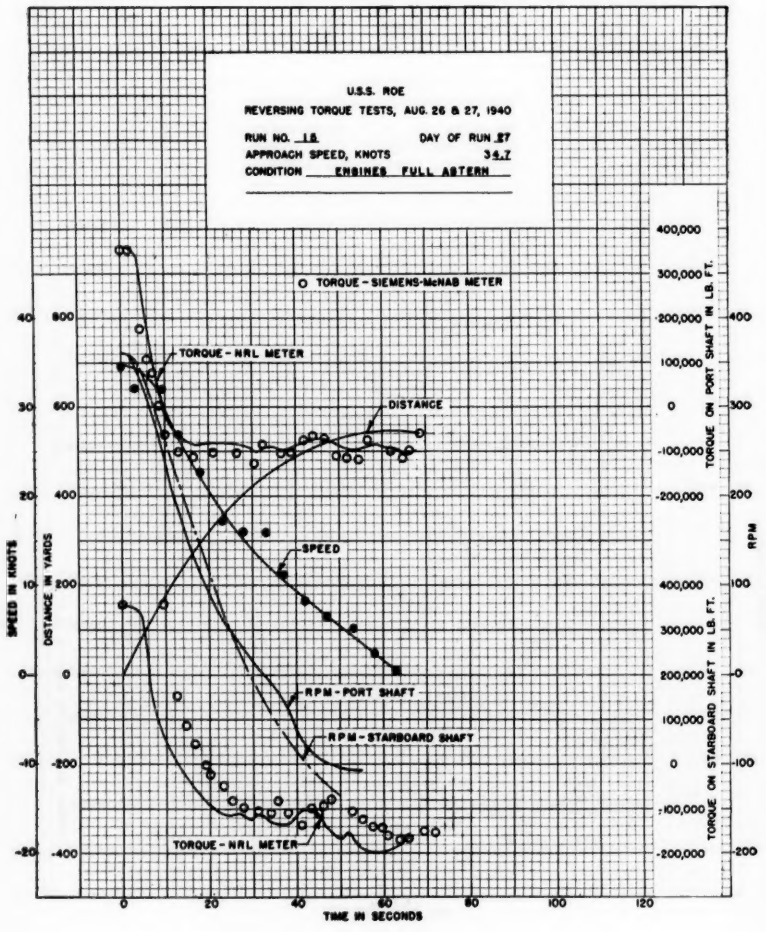


FIGURE 13.
Record of crash astern run from 34.7 knots.

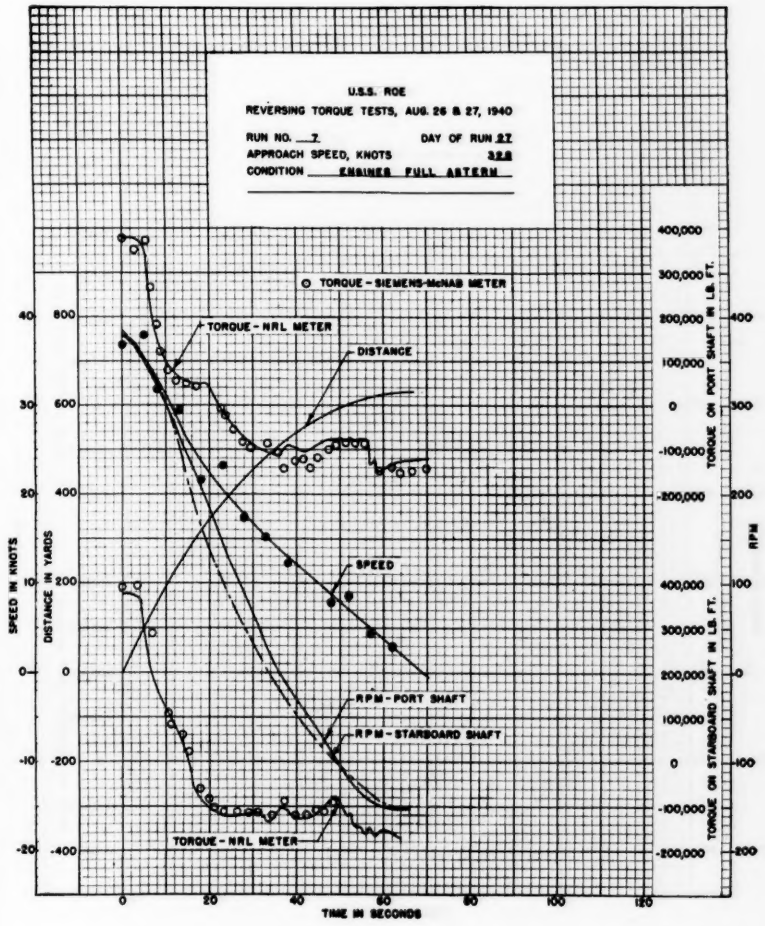


FIGURE 14.
Record of crash astern run from 32.8 knots.

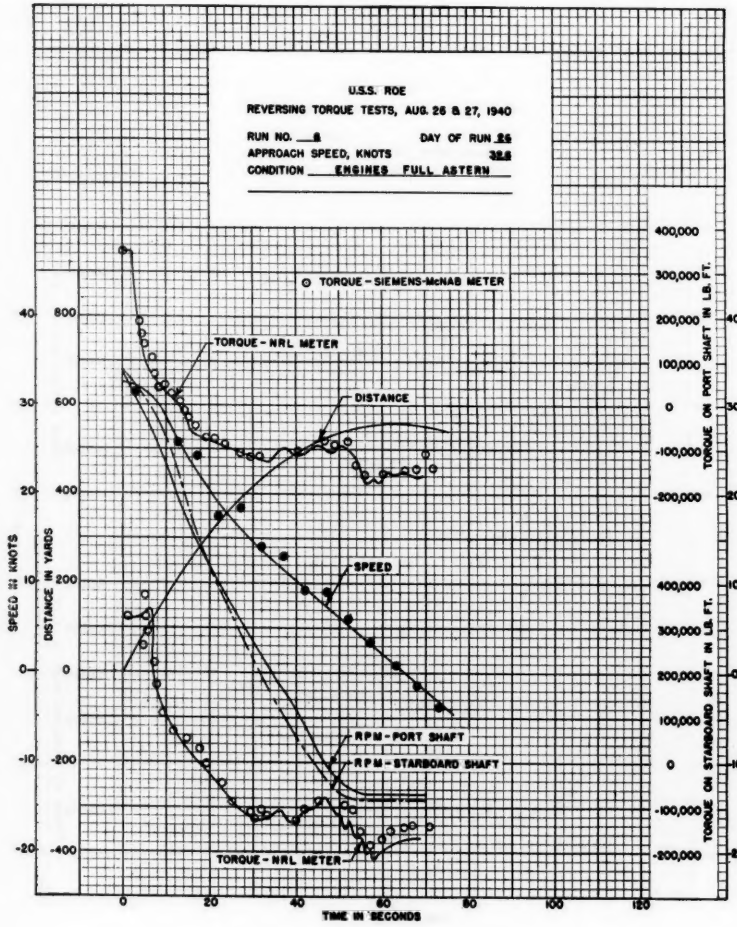

U.S.S. ROE
REVERSING TORQUE TESTS, AUG. 26 & 27, 1940
RUN NO. 6 DAY OF RUN 26
APPROACH SPEED, KNOTS 32.6
CONDITION ENGINES FULL ASTERN
⊙ TORQUE - SIEMENS-McNAB METER
TORQUE - NRL METER
DISTANCE
SPEED
RPM - PORT SHAFT
RPM - STARBOARD SHAFT
TORQUE - NRL METER
SPEED IN KNOTS
DISTANCE IN YARDS
TORQUE ON PORT SHAFT IN LB. FT.
TORQUE ON STARBOARD SHAFT IN LB. FT.
RPM
TIME IN SECONDS

FIGURE 15.
Record of crash astern run from 32.6 knots.

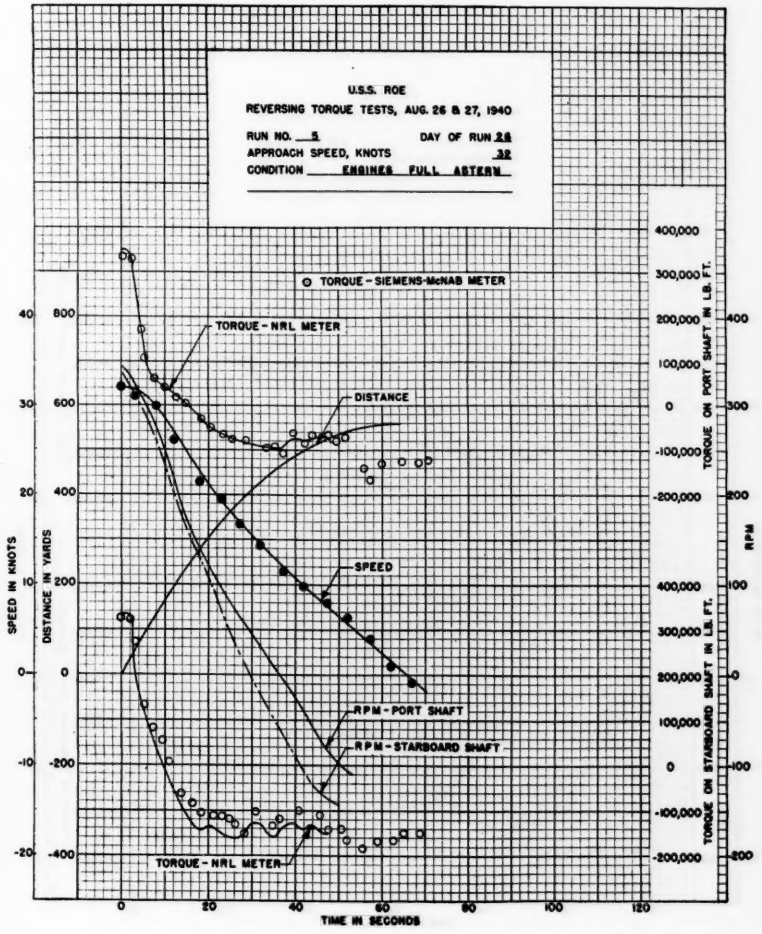


FIGURE 16.
Record of crash astern run from 32 knots.

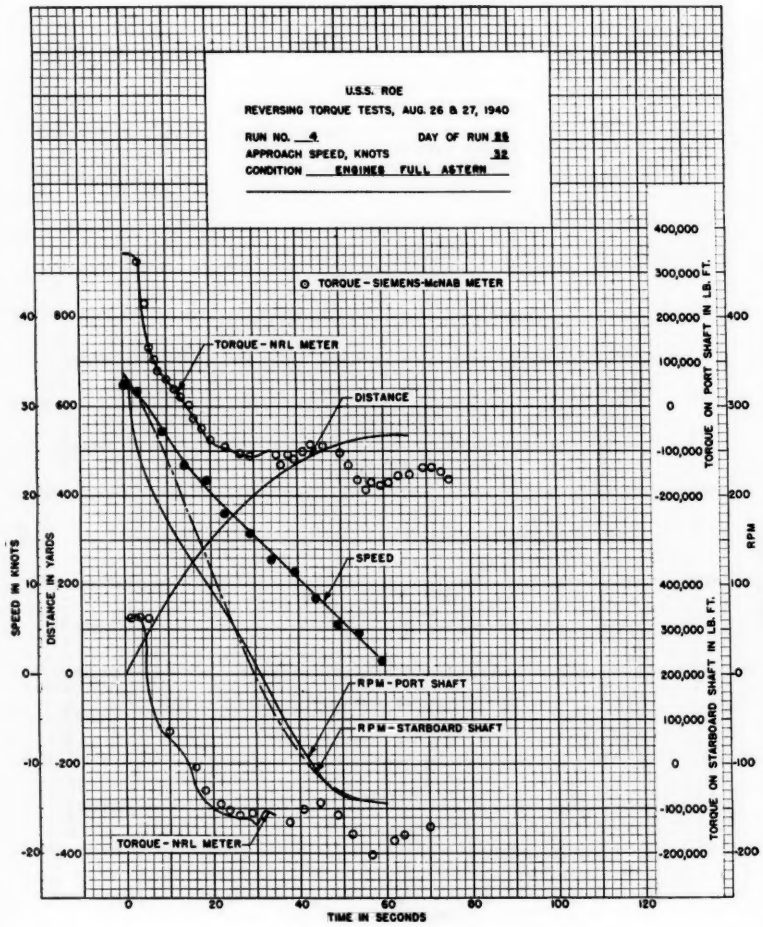


FIGURE 17.
Record of crash astern run from 32 knots.

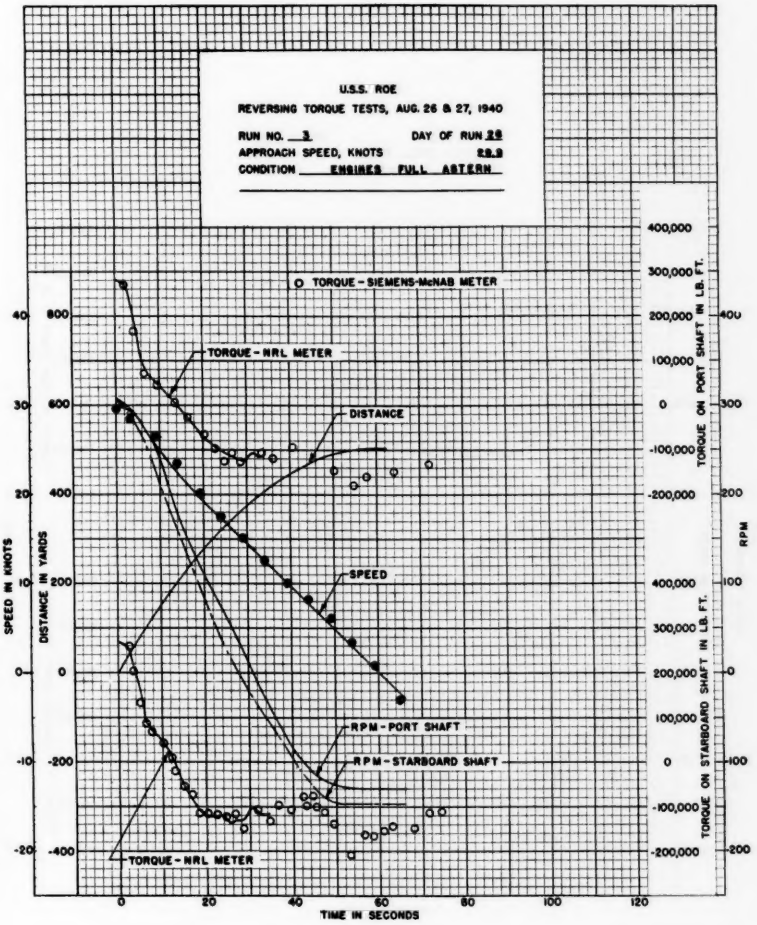


FIGURE 18.
Record of crash astern run from 29.9 knots.

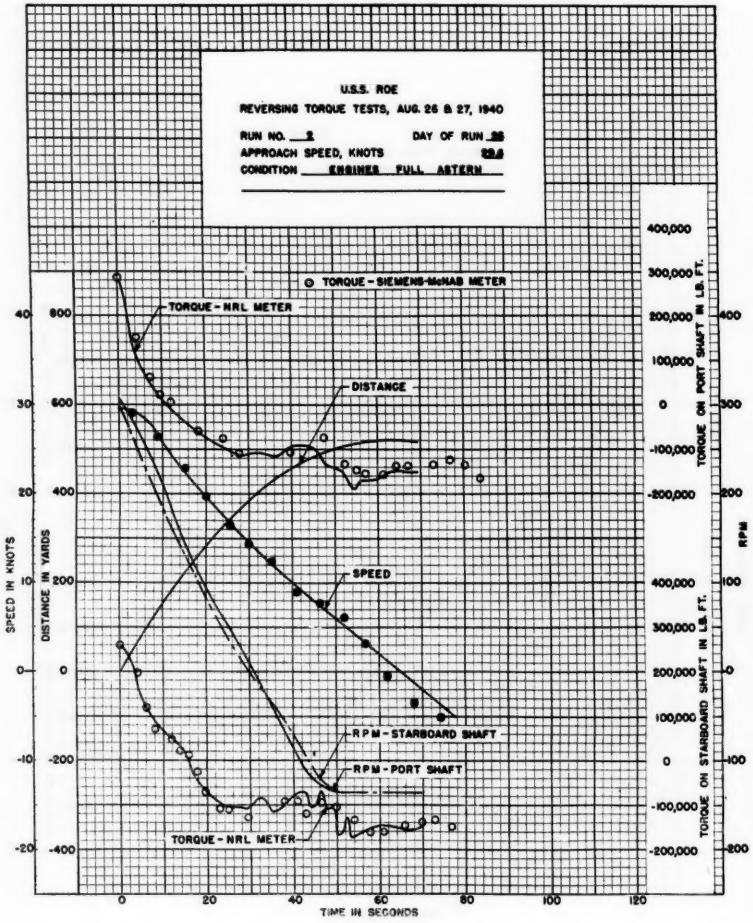


FIGURE 19.
Record of crash astern run from 29.6 knots.

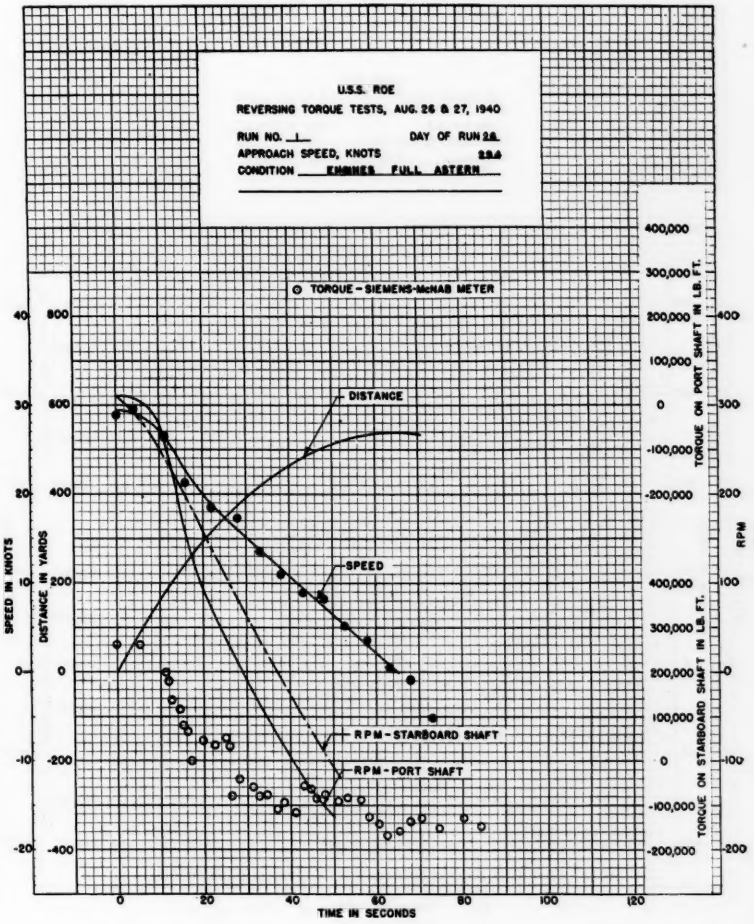


FIGURE 20.

Record of crash astern run from 29.4 knots. (Port shaft torque not obtained.)

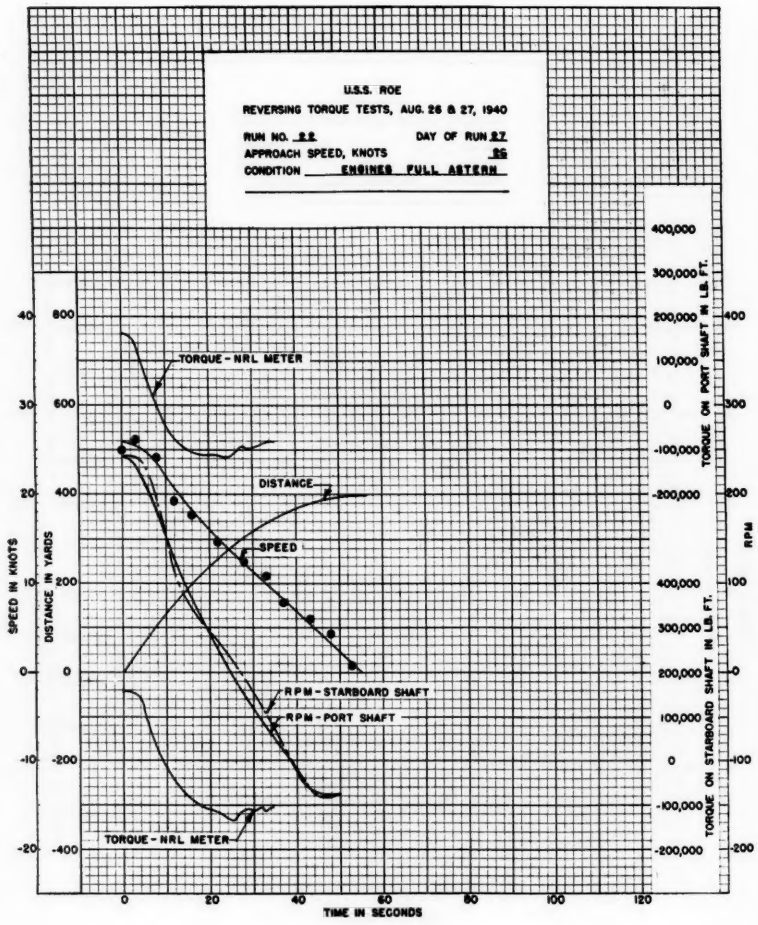


FIGURE 21.
Record of crash astern run from 26 knots.

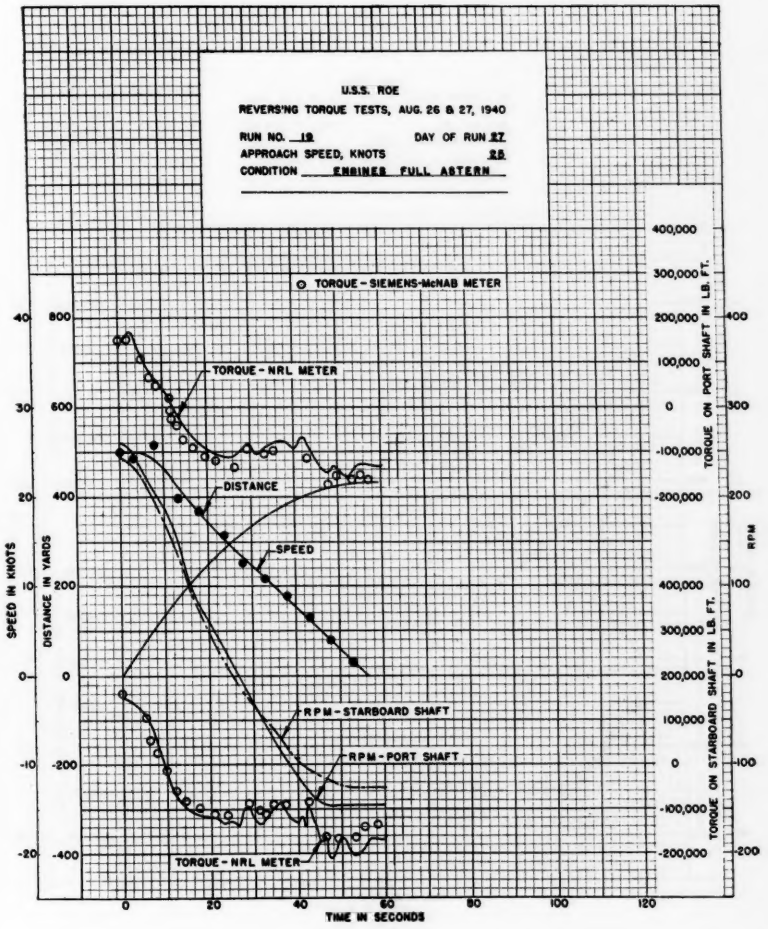


FIGURE 22.
Record of crash astern run from 25 knots.

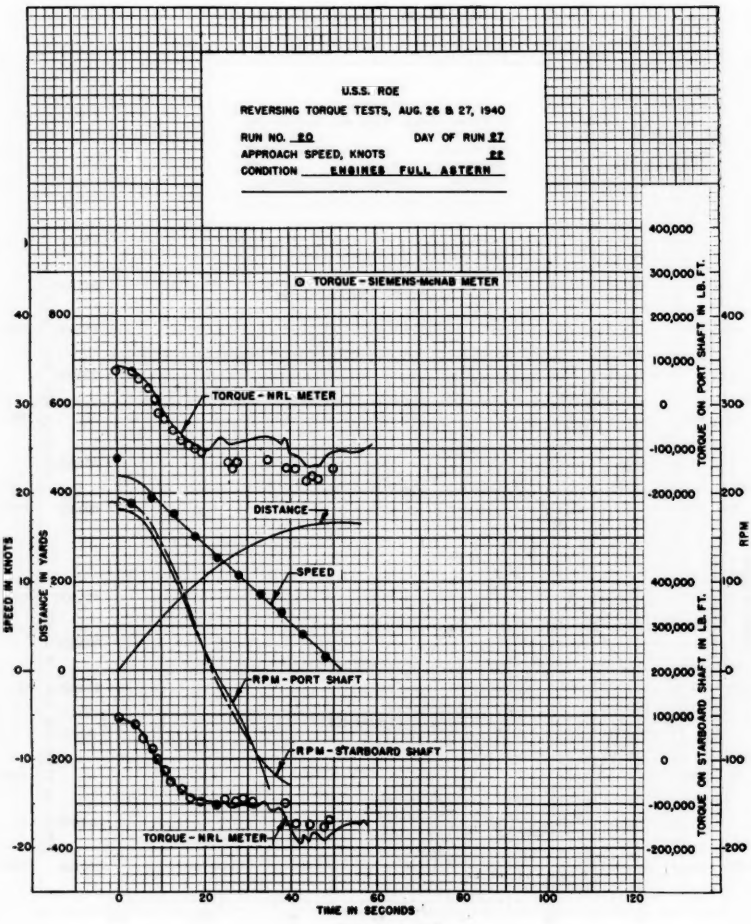


FIGURE 23.
Record of crash astern run from 22 knots.

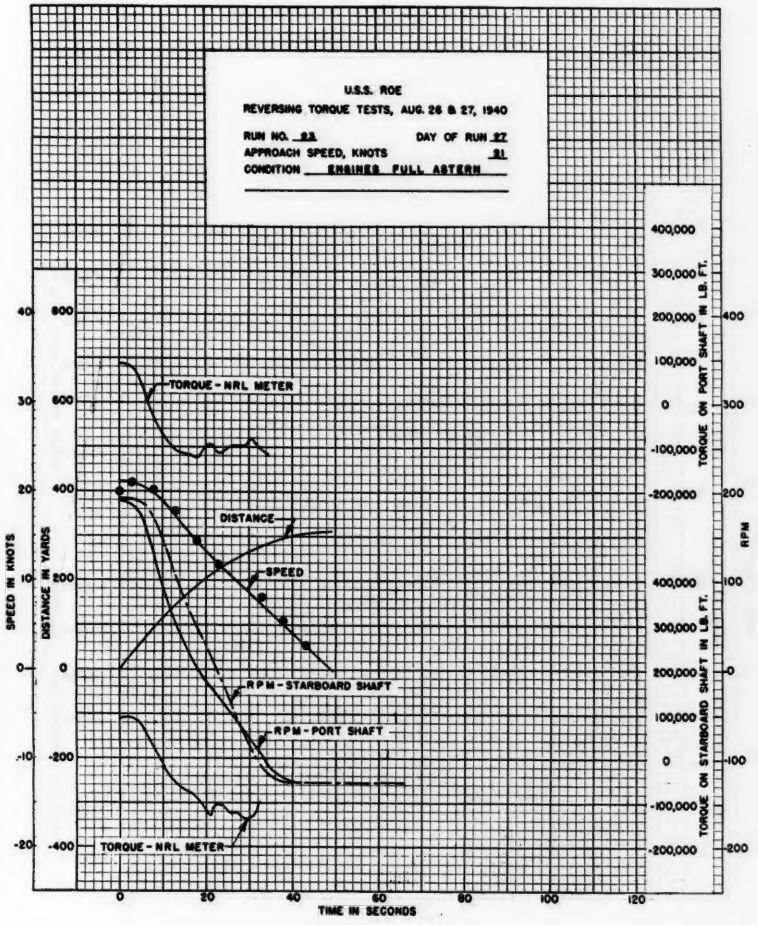


FIGURE 24.
Record of crash astern run from 21 knots.

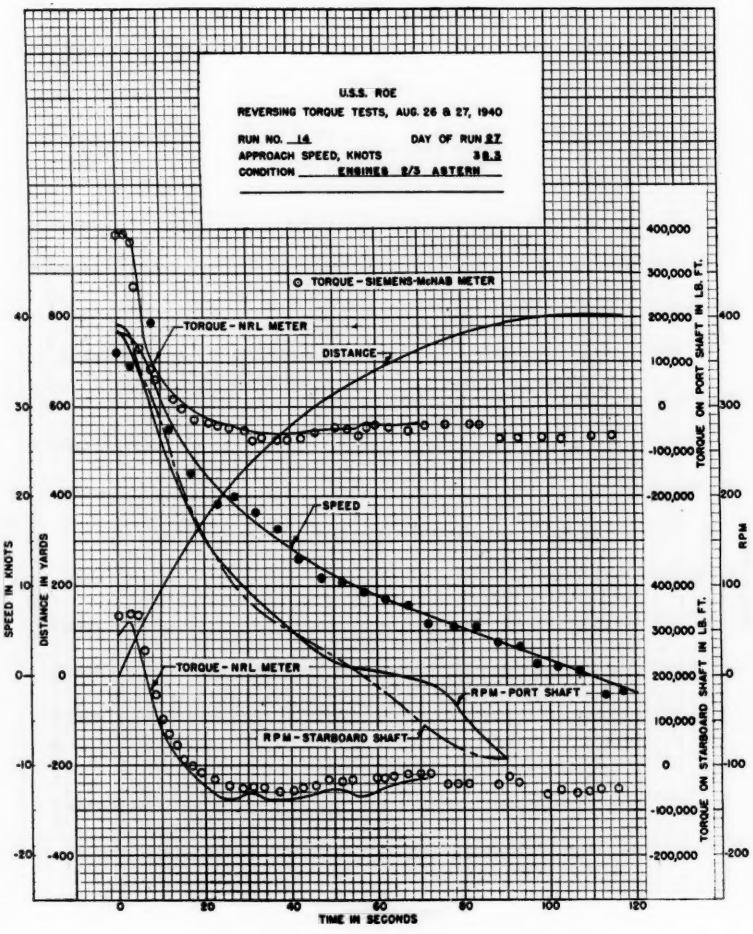


FIGURE 25.
Record of two-thirds astern run from 38.3 knots.

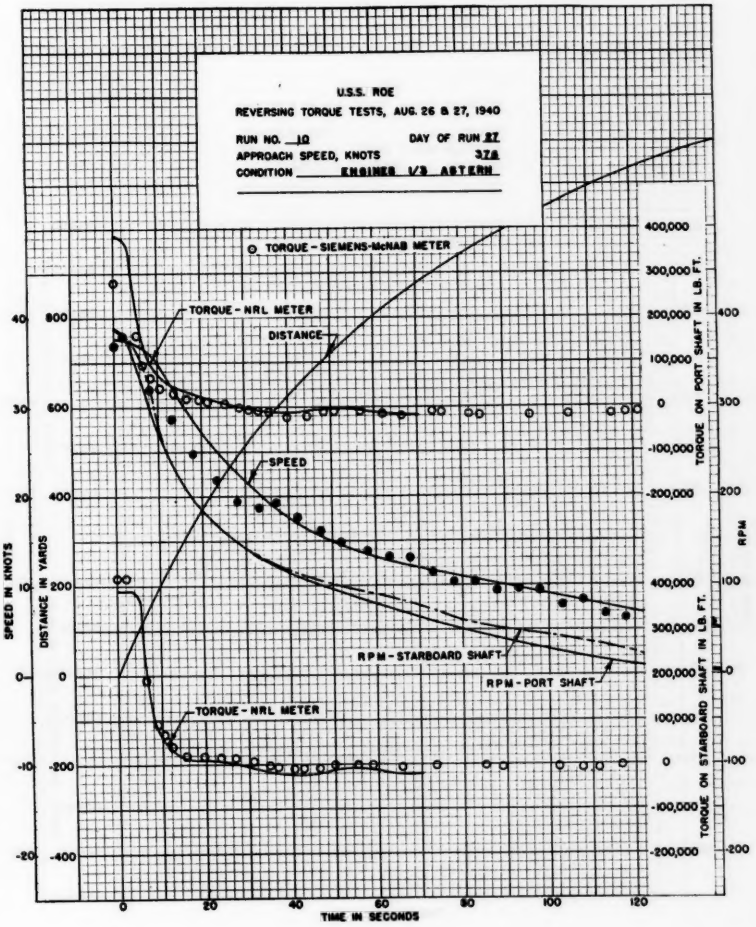


FIGURE 26.
Record of one-third astern run from 37.6 knots.

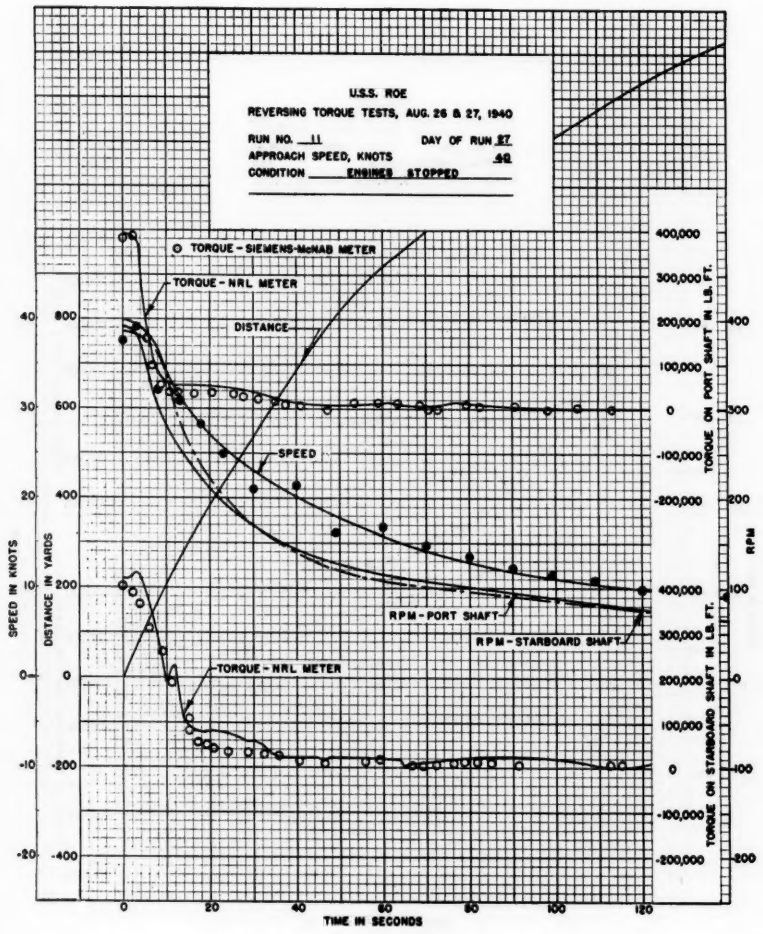


FIGURE 27.
Record of normal deceleration run from 40 knots.

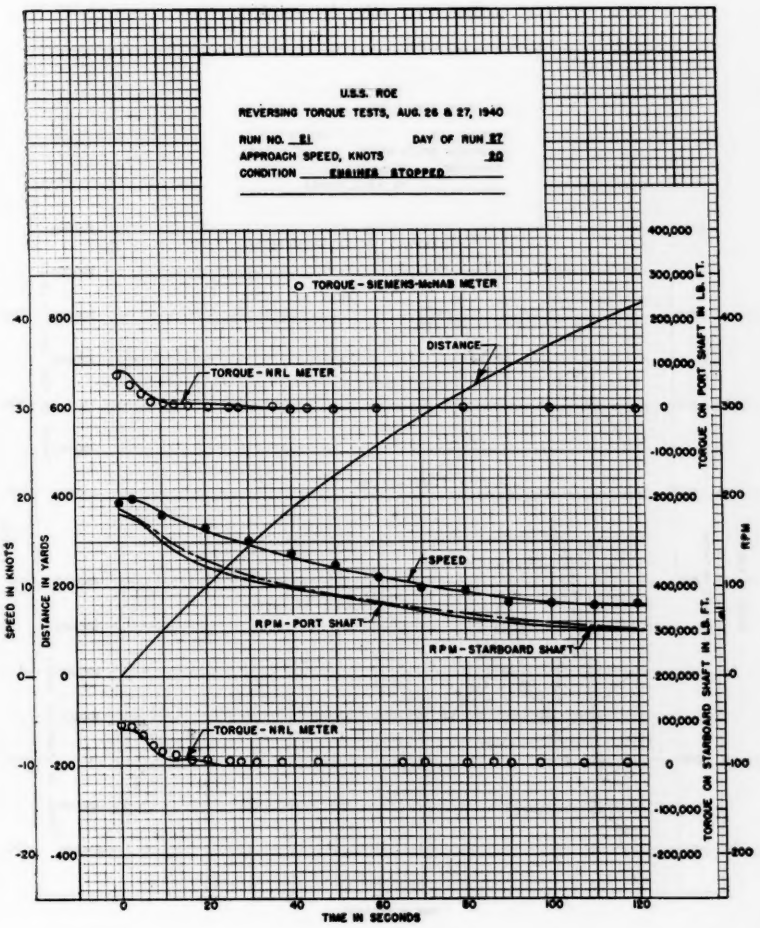


FIGURE 28.
Record of normal deceleration run from 20 knots.

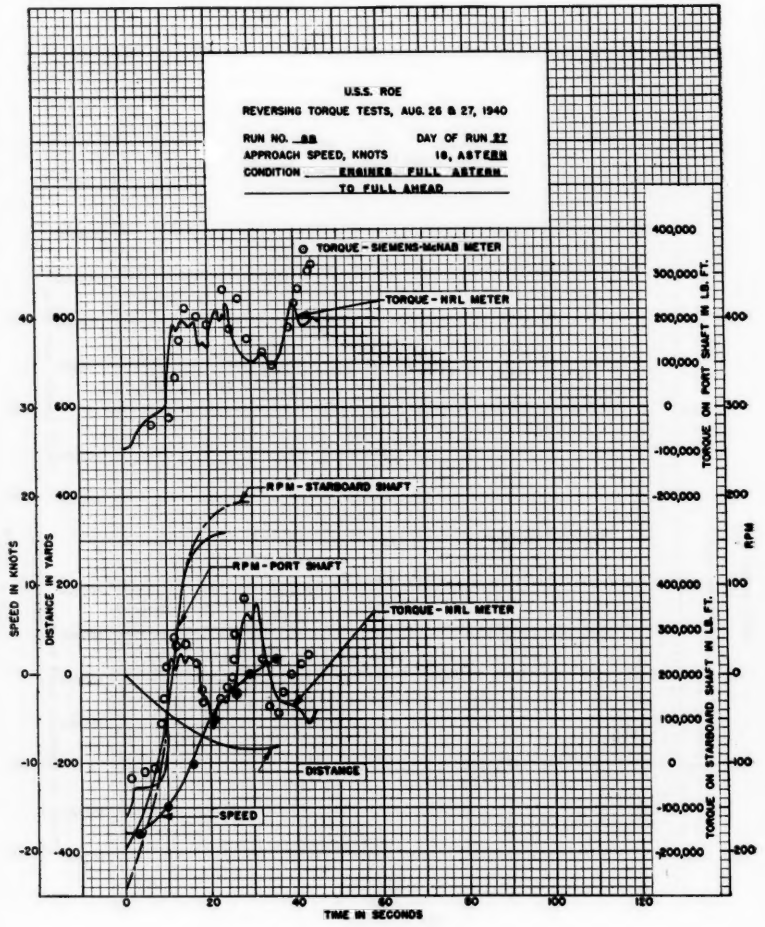


FIGURE 29.
Record of crash ahead run from 18 knots astern.

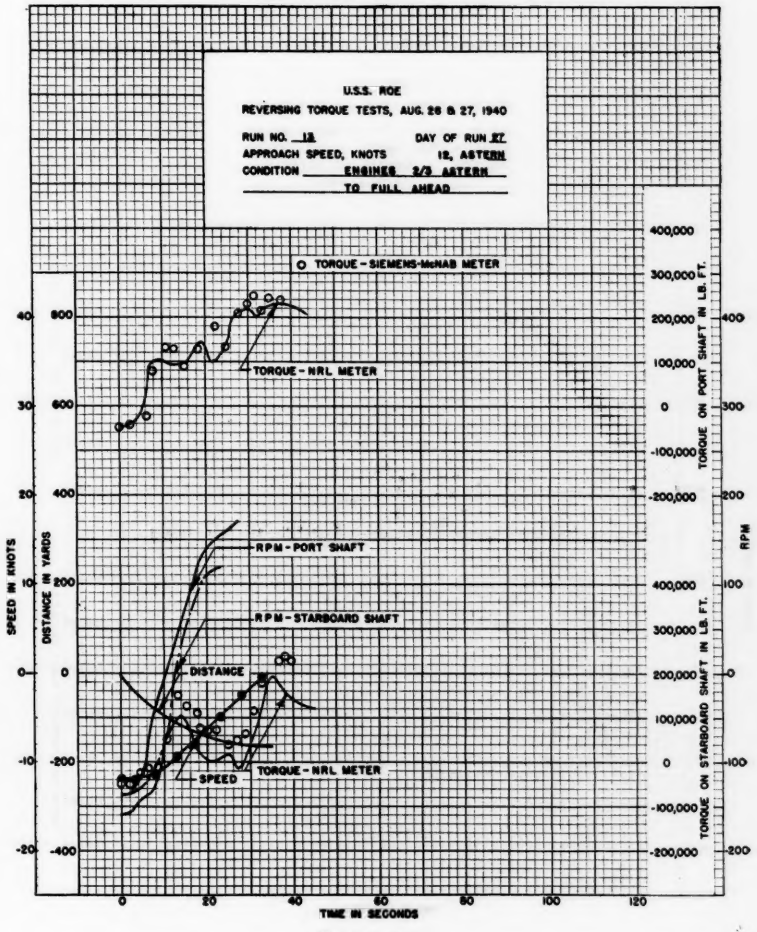

U.S.S. ROE
REVERSING TORQUE TESTS, AUG. 26 & 27, 1940
RUN NO. 18 DAY OF RUN 27
APPROACH SPEED, KNOTS 12, ASTERN
CONDITION ENGINES 2/3 ASTERN TO FULL AHEAD
TORQUE - SIEMENS-McNAB METER
TORQUE - NRL METER
RPM - PORT SHAFT
RPM - STARBOARD SHAFT
DISTANCE
SPEED
TORQUE - NRL METER
SPEED IN KNOTS
DISTANCE IN YARDS
TORQUE ON PORT SHAFT IN LB. FT.
TORQUE ON STARBOARD SHAFT IN LB. FT.
RPM
TIME IN SECONDS

FIGURE 30.
Record of crash ahead run from 12 knots astern.

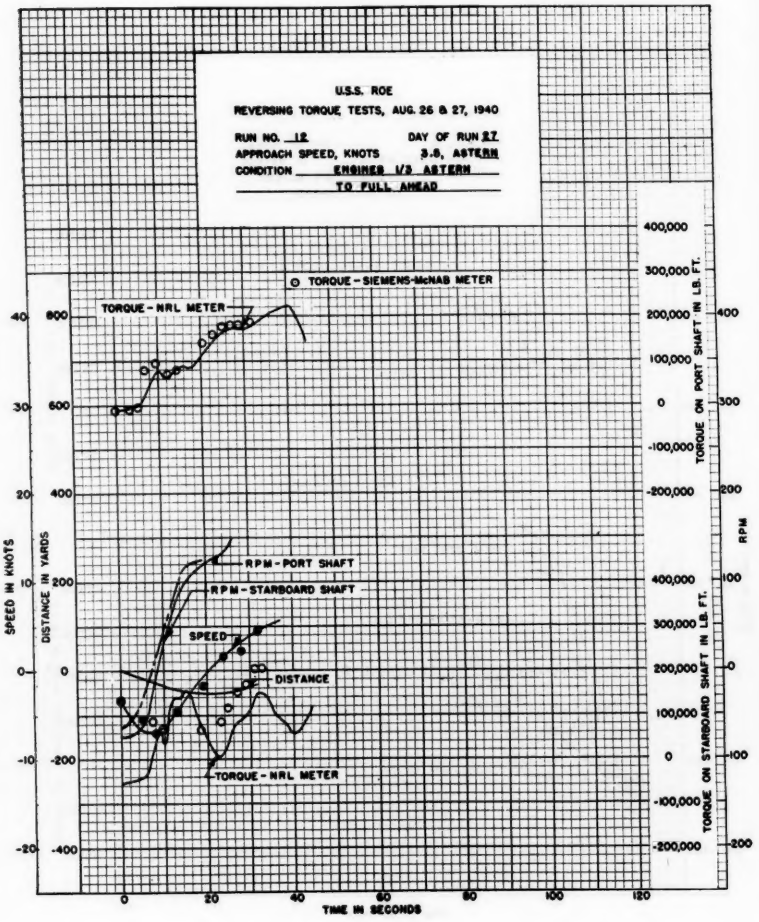


FIGURE 31.
Record of crash ahead run from 3.5 knots astern.

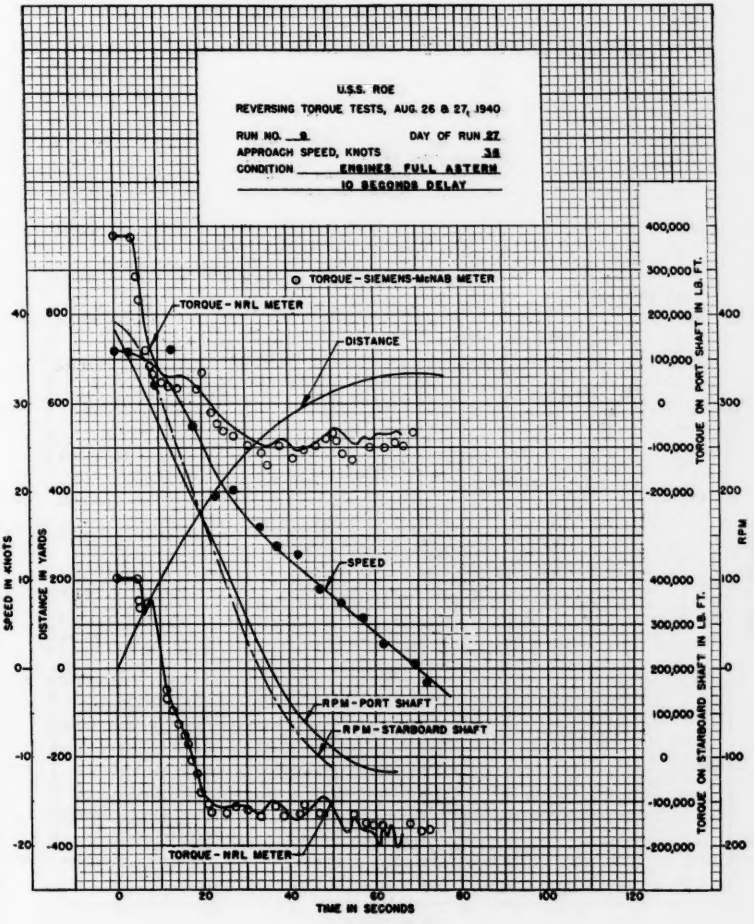


FIGURE 32.

Record of crash astern run from 36 knots with 10 seconds interval between time ahead throttle was closed and astern throttle was opened.

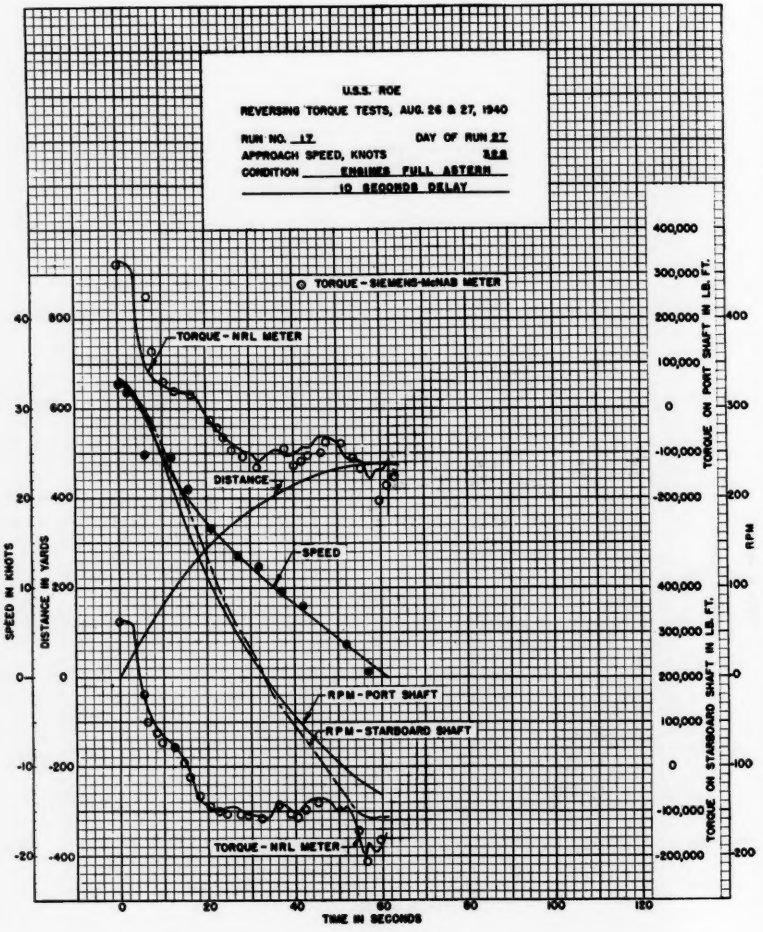


FIGURE 33.

Record of crash astern run from 32.8 knots with 10 seconds interval between time ahead throttle was closed and astern throttle was opened.

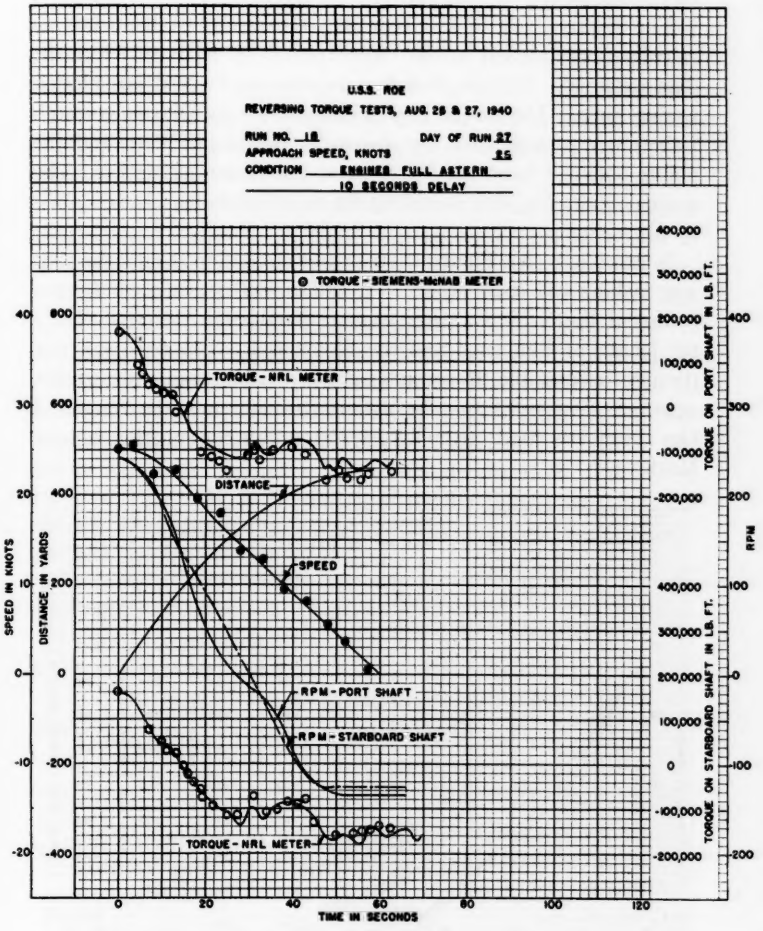


FIGURE 34.

Record of crash astern run from 25 knots with 10 seconds interval between time ahead throttle was closed and astern throttle was opened.

was rapidly closed, and a ten-second interval was allowed to elapse before the astern throttle was opened, Figures 32 to 34, inclusive.

The Figures (11 to 34) represent the results of the trials as calculated and plotted by the Experimental Model Basin from the data obtained. Torque, R.P.M., distance, and speed are plotted against time. The torque curves obtained by the Naval Research Laboratory torsionmeter are shown as continuous lines and the points obtained from the Ford meter are shown as circles. The speeds obtained by differentiating the recorded distances are shown by black dots.

In run No. 8 (a), Figure 11, the run was continued until the ship was making full speed astern. It will be noted that a continuous record of the N. R. L. meter was not obtained. This was due to the length of film used and the film speed. The film was run through once at the 35 seconds speed, rewound and run through again at that speed. For the majority of the runs, the 70-second film speed was used. Run No. 8 (b) was a continuation of run No. 8 (a).

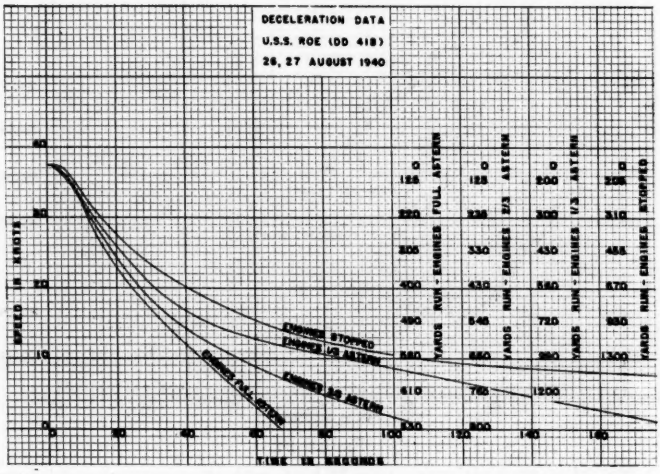


FIGURE 35.

Comparative deceleration data including a typical crash astern run, the two-thirds astern run, the one-third astern run, and the normal deceleration, all corrected to an initial speed of 37.4 knots.

The deceleration data shown on Figure 35 compares a typical full astern speed curve to the two-thirds astern, one-third astern and normal deceleration curves. The head reach in each case is also given. The steam pressures used for all full astern runs was approximately 250 pounds per square inch, for the two-thirds astern approximately 150 pounds, and for the one-third astern approximately 50 pounds. No record of instantaneous steam chest pressure could be obtained.

Figure 36 represents deceleration curves obtained by differentiating the speed curves. A number of typical curves were used to obtain the upper curve, the full astern deceleration. The two normal deceleration curves were used to obtain the lower curve. The points calculated for plotting these curves were very consistent. It is of interest to note that the points obtained from the high-speed runs and the lower-speed runs were practically identical. That is, at fifteen knots the deceleration was the same whether the run had started at 35 knots or at 25. This fact was true of both the full astern deceleration as well as the normal deceleration. The dotted curve on Figure 36 is the calculated deceleration using the model effective horsepower. It is interesting to note the close similarity between these two curves.

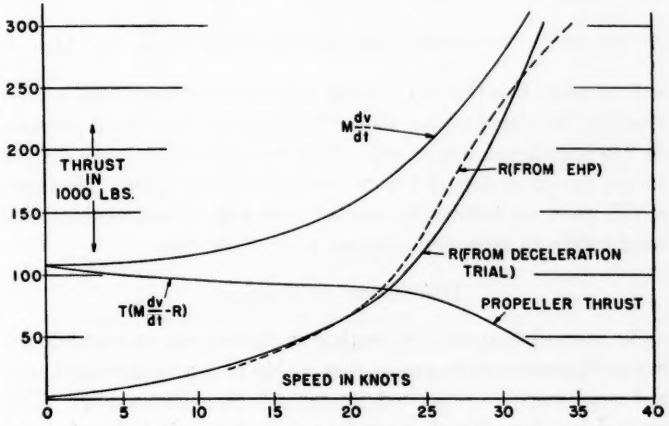


FIGURE 36.
Plot of force curves of the Ship-Mass System.

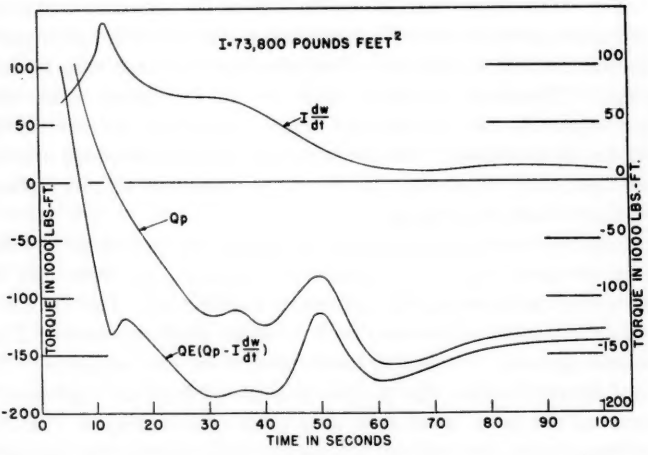


FIGURE 37.
Plot of torque curves of one rotating-mass system.

Figure 37 represents a typical torque curve "Q_p," a torque curve "$I\frac{d\omega}{dt}$," obtained by differentiation of a typical R.P.M. curve, and the turbine torque curve obtained by adding "$I\frac{d\omega}{dt}$" to "Q_p." It will be noted that the "Q_e" curve so obtained is somewhat greater than the calculated torque shown in Figure 2 for a steam pressure of 250 pounds per square inch. Test measurements of the turbine torque shown on Figure 2 were made at only one point. However, at this point the test results checked well with the calculations, and were within an estimated accuracy of $\pm$ 5 per cent.

DISCUSSION OF RESULTS.

As heretofore stated, the method in present use to calculate the reversing torque necessary to stop a ship in a predetermined time and head-reach is described in (a) of the bibliography. This method has been found generally satisfactory. It is based, however, upon model tests and trials of a limited number of ships and

does not differentiate between different hull characteristics, nor propeller characteristics. In order to evaluate the effects of these variables, additional tests and trials are necessary. The trial described herewith is representative of high-speed vessels of similar hull, power, and propeller characteristics.

The curves shown on the Figures 6 to 36 inclusive represent averaged value and small variations are thereby eliminated. The result of this process, while simplifying the analysis, is approximate. The dots were included on the speed curve to indicate the order of these variations. The " distance " curve was obtained by integrating the faired speed curve.

Figures 11 to 24, the results of the normal " crash astern " runs, are in general consistent. A tabulation of these runs is shown below. It will be noted that for this ship the maximum astern torque is little effected by the ahead speed from which the run is started.

Figure	*Run No.*	*Speed*	*Time to Stop Shaft*	*Time to Stop Ship*	*Head Reach*	*Maximum Astern Torque (Av. of two shafts) (Approximate)*
11	8a	36.2	35 Sec.	65.5 Sec.	627 Yds.	160,000
12	16	34.8	30.5 Sec.	64 Sec.	620 Yds.	190,000
13	15	34.7	31 "	64 "	545 "	155,000
14	7	32.8	35 "	69 "	630 "	160,000
15	6	32.6	33 "	65 "	558 "	190,000
16	5	32	33 "	66 "	560 "	190,000
17	4	32	30.5 "	62.5 "	535 "	195,000
18	3	29.9	29.5 "	60 "	505 "	190,000
19	2	29.6	30.5 "	65 "	520 "	180,000
20	1	29.4	33 "	65 "	540 "	170,000
21	22	26	26 "	55 "	400 "	.....
22	19	25	26 "	56.5 "	430 "	185,000
23	20	22	22 "	52 "	335 "	170,000
24	23	21	21 "	49 "	310 "	.....

The runs plotted in Figures 25 and 26 were conducted in order to determine the effect of decreased available astern torque. The reduction in astern torque to approximately 75,000 pounds foot increased the time to stop the ship from about 65 seconds to 110 seconds and increased the head reach from about 625 yards to 805 yards. When the trial procedure was decided

upon, it was not realized that the one-third astern steam pressure of 50 pounds per square inch would produce so low a torque. These runs do, however, emphasize the importance of sufficient reversing torque. Comparison of these runs with the tabulations above show that there is no general relation between the ahead speed at which reversal is commenced and the torque requirements.

The runs plotted in Figures 27 and 28 represent the normal deceleration of the ship from a high and relatively low speed. The deceleration rate at the same speeds calculated from these two runs were practically identical. The calculated speed of 40 knots shown on Figure 27 is undoubtedly in error, however, the plotted positions as photographed have been checked and the error cannot be found. The curve, therefore, has not been corrected.

The runs plotted in Figures 29, 30 and 31 were held to determine the torques obtained during "crash ahead" conditions. It is interesting and somewhat surprising to note that at no time did the torque exceed full power ahead torque. That this result can be applied to other ships is doubtful. The propellers were probably cavitating during this period, and from the disturbed condition of the water, were undoubtedly receiving air in the propeller suction. This air would have had the same general effect as cavitation.

The runs plotted in Figures 32, 33, and 34 were conducted to determine the effect of a slow operating throttle, or the reverse, the necessity for rapid manipulation of the throttles. These runs were conducted in exactly the same manner as the normal "crash astern" runs except that a ten-second interval was allowed to elapse between closing the ahead throttle and opening the astern throttle.

Crash astern with 10 seconds delay.

Figure	*Run No.*	*Speed*	*Time to Stop Shaft*	*Time to Stop Ship*	*Head Reach*	*Maximum Astern Torque*
32	9	36	34.5 Sec.	69.5 Sec.	670 Yds.	150,000
33	17	32.8	33 "	61 "	475 "	180,000
34	18	25	29 "	60 "	455 "	170,000

Crash astern—normal—repeated from first tabulation. For comparison.

Figure	*Run No.*	*Speed*	*Time to Stop Shaft*	*Time to Stop Ship*	*Head Reach*	*Maximum Astern Torque*
11	8a	36.2	35 Sec.	65.5 Sec.	627 Yds.	160,000
14	7	32.8	35 "	69 "	630 "	160,000
22	19	25	26 "	56.5 "	430 "	185,000

It will be noted that, in spite of some inconsistencies, such as the excessive head reach of run No. 7 (Figure 14) there is in general no great necessity of hurried operation of the throttles. The deceleration data curves shown in Figure 35 indicate that for this ship there is no great difference between the deceleration rates during the first ten seconds.

Figures 36 and 37 represent the force curves of the two systems, (1) the ship mass, and (2) the rotating mass. The data were obtained for calculating these curves from representative or averaged plots. The natural deceleration was used to obtain the hull resistance " R." The difference between the total force on " $M\frac{dV}{dt}$ " curve and the " R " values was used to determine the thrust. The engine torque " Q_e" was likewise obtained by adding the torque of the propeller shaft " Q_p" obtained from the torsionmeters to the calculated inertia torque " $I\frac{d\omega}{dt}$." The propeller inertia and the inertia of the shaft between the torsionmeter and the propeller were neglected as they were insignificant when compared with the other torques involved.

Calculations of $\frac{TD}{Q}$ resulted in irregular values for that interval of time when the torque was erratic. This would be expected as the thrust was obtained by subtracting the faired curve of the normal decelerating force from the full-speed astern decelerating force. The result was necessarily a fair curve, while the torque as measured was very irregular. During the relatively steady conditions, the value of $\frac{TD}{Q}$ equalled approximately 4.2. When corrected for thrust deduction, this agrees fairly well with the model results obtained by Conn, (c).

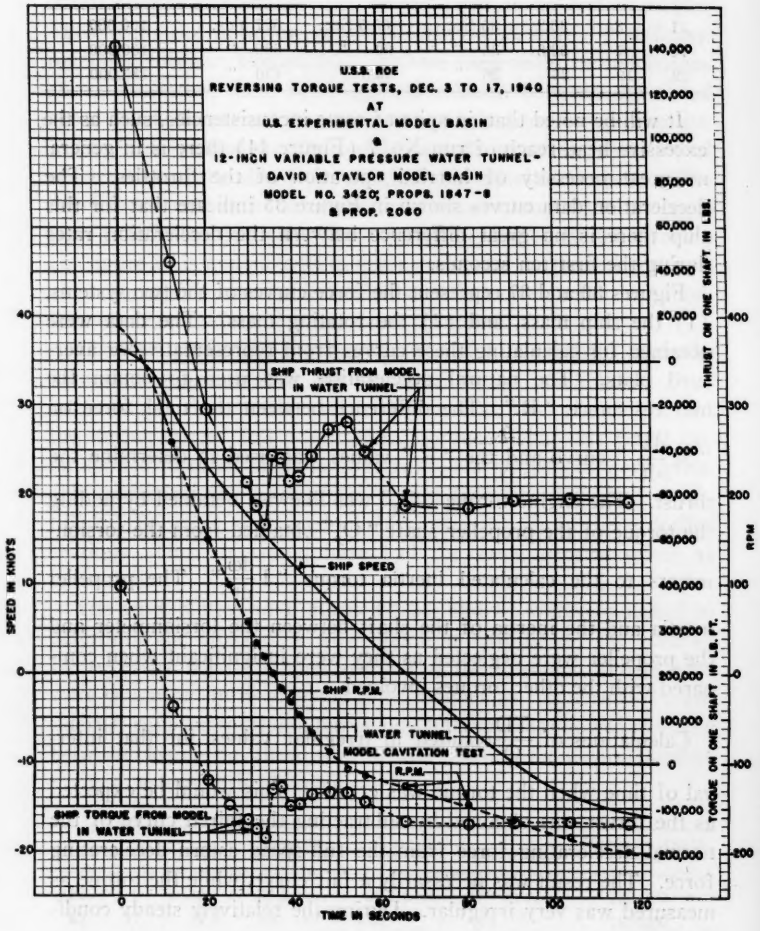

U.S.S. ROE
REVERSING TORQUE TESTS, DEC. 3 TO 17, 1940
AT
U.S. EXPERIMENTAL MODEL BASIN
&
12-INCH VARIABLE PRESSURE WATER TUNNEL -
DAVID W. TAYLOR MODEL BASIN
MODEL NO. 3420; PROPS. 1847-S
& PROP. 2060
SHIP THRUST FROM MODEL IN WATER TUNNEL
SHIP SPEED
SHIP R.P.M.
WATER TUNNEL MODEL CAVITATION TEST R.P.M.
SHIP TORQUE FROM MODEL IN WATER TUNNEL
SPEED IN KNOTS
THRUST ON ONE SHAFT IN LBS.
TORQUE ON ONE SHAFT IN LB. FT.
RPM
TIME IN SECONDS

FIGURE 38.

Record of model test including averaged thrust and torque of the propellers. Representative speeds and revolutions were obtained from a typical trial crash astern run.

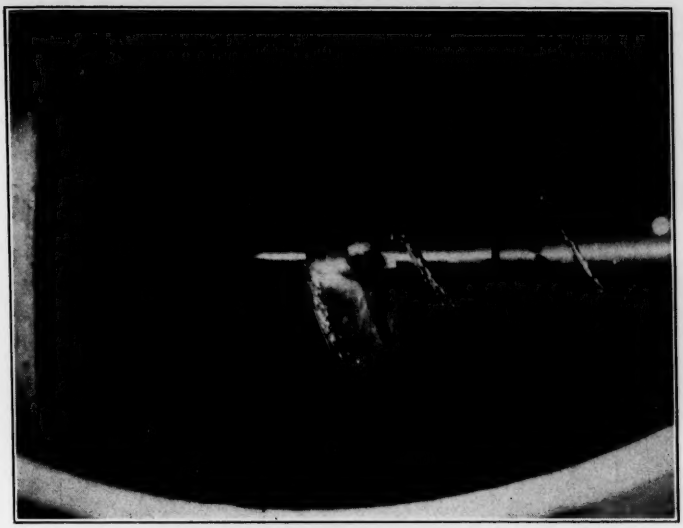


FIGURE 39.

Stroboscopic photograph of propeller with negative slip. The water velocity is from left to right. The propeller rotation is clockwise when facing the direction of flow. This photograph represents an attempt to simulate a ship's speed of 17.5 knots ahead with the propellers rotating ahead at 55 R. P. M.

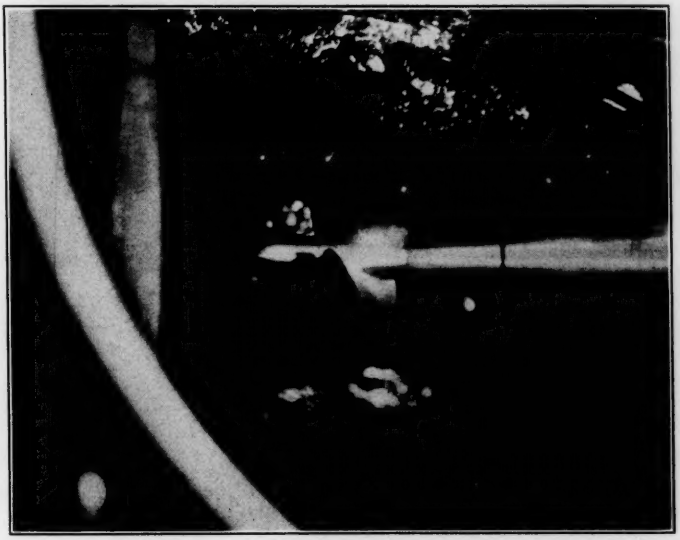


FIGURE 40.

Stroboscopic photograph of propeller just prior to the moment air was obtained from the surface. The flow is from left to right, and the propeller rotation is now counter clockwise. This photograph represents an attempt to reproduce the condition of the ship moving ahead and the propeller reversing at slow revolutions.

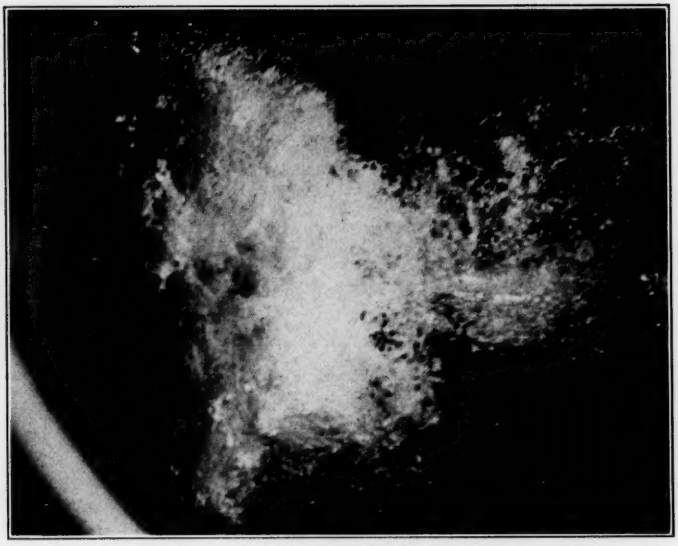


FIGURE 41.

Stroboscopic photograph of propeller enveloped by air drawn from the surface. The conditions are the same as in figure 40.

Self-propelled model tests were conducted in an attempt to simulate the conditions existing during stopping and backing. Figure 38, the record of the results obtained, is in general agreement with the trial results. At approximately the same relative time that the trial torque became erratic, the model propellers developed a depression in the water surface and drew air into the propeller suction. This fact leads to the conclusion that the ship's propeller obtained air from the surface in a similar manner.

Model tests were conducted in the 12-inch variable pressure tunnel with the same propellers used on the self-propelled tests. The results were so inconsistent that it was suspected that the wall effect was disturbing the flow and similitude of flow was thereby destroyed. To avoid wall effect, a 4-inch model propeller was made and tested. This propeller gave consistent results; however, due to the low Reynolds number, these results cannot be accepted without verification. During the tests of this 4-inch propeller, very little cavitation could be seen with the stroboscopic light used, and no effects of cavitation could be noted in the torque and thrust measurements within the range covered by these tests. When the water level was lowered to that representing the tip emersion of the ship's propeller, a similar depression appeared on the surface to that noted on the self-propelled model tests, and the propeller became completely enveloped with air. Both self-propelled tests and variable pressure tunnel tests indicate that the torque and thrust were considerably affected by air drawn from the surface. The photographs, Figures 39 to 41, are included to illustrate the effects of cavitation or air under these transient conditions. Similitude of flow undoubtedly did not exist and therefore these photographs do not represent exact conditions as they exist on the full scale ship. The fact that little cavitation was evident may be explained by the relatively low velocities existing at the low revolutions. Refer to Smith (g) and Dodson (h) for a complete explanation of these phenomena.

Conclusions.

The deceleration is unaffected by the speed at which backing is commenced and depends only on the instantaneous speed and pro-

peller thrust. Differentiation of the plot of high and low speed runs produced identical results.

The maximum astern torque likewise is unaffected by the speed at which backing is commenced. On these trials approximately the same maximum torque was obtained regardless of the original speed.

The normal deceleration calculated from the model effective horsepower is sufficiently accurate for the purpose of estimating stopping characteristics. The normal deceleration obtained from the trial data and that calculated from model EHP produced results within the order of accuracy of these data.

Propeller tip emersion is an important factor in estimating torque during the stopping and backing process. During these trials, air, drawn from the surface, unloaded the propellers and prevented high torque from occurring.

There is in general no necessity for hurried operation of the astern throttle. If the ahead throttle is closed immediately, the ship will decelerate rapidly. The ten seconds allowed on runs 9, 17 and 18 between the time the ahead throttle was closed and the astern opened had little effect on the time to stop the ship and on the head reach.

For the purpose of making preliminary estimates of stopping and backing characteristics the following values of $\frac{TD}{Q}$ may be used with acceptable accuracy.

$\frac{TD}{Q} = 5$ where " T " equals propeller thrust.

$\frac{TD}{Q} = 4$ where " T " equals " effective " thrust
(or propeller thrust corrected for thrust deduction).

From the results of these trials and model tests, it is concluded that the trials described herewith can be applied only to ships of similar hull and propeller, and otherwise complying with the requirements for geometric and dynamic similitude. Due to the numerous important variables involved, accurate prediction of head

reach and the time to stop a ship must at present be based upon full scale trials. Additional trials of ships, of characteristics differing from that of this destroyer, are needed.

In addition to the information obtained on these destroyer trials, means for recording instantaneous thrust and ship's speed should be provided. Likewise, for turbine drive, astern steam pressure in the nozzle chest should be recorded, and for other types of drive, means for determining the engine torque.

ACKNOWLEDGMENT.

The writer wishes to express appreciation to the personnel of the various agencies who made the successful completion of these trials and these results possible:

The Experimental Model Basin
The Naval Research Laboratory
New York Navy Yard
The Commanding Officer, Officers and Crew of the U. S. S. *Roe*
Gibbs and Cox, Inc.
Westinghouse Electric and Manufacturing Company.

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DISCUSSION

By Captain Lybrand P. Smith, U. S. N., Member, of Commander Gold's Paper

"STOPPING AND BACKING TRIALS OF A DESTROYER."

The ability to stop and back a ship is of vital importance to the mariner. Consequently, it is of vital importance to the ship and engine designer. Owing to the transient nature of the phenomena involved, it is an exceptionally difficult subject upon which to obtain reliable experimental data. During the past quarter of a century a number of important papers on this subject have appeared, and generally each paper has been an improvement over its predecessors. The improvements have usually resulted because more or better instruments enabled observations to be substituted for some of the assumptions which earlier writers were compelled to use.

Commander Gold's paper is the best to date. This not only results from better instrumentation, meticulous care in taking observations, and careful analytical study. It also results from his experiment being performed on an actual ship and from the wealth of data and descriptions of test procedure presented.

Model tests are not satisfactory for obtaining stopping and backing data. It is not merely that obtaining records of transient phenomena during accelerated motion is difficult on the model, for it is nearly as difficult on a ship. The main reason is because it is almost impossible to have dynamic similarity between the propulsion apparatus of the ship and the model, or to make corrections for the lack of such similarity during acceleration. Even if inertia effects are calculated for the propulsion apparatus, frictional differences under such circumstances would cast doubt on

the total results. Moreover, the rigidity of the model differs greatly from that of the ship, and results in radically different vibration phenomena.

Because of such difficulties with accelerated motion model tests are almost invariably run in a state of steady motion. A series of points is observed for a number of runs of different but uniform velocities. It is then assumed that we can apply a time rate of change to these various velocities, and predict what would happen if the model were actually accelerated. This assumption is highly dubious, because it is based on a number of other dubious assumptions, among which are the four following:

First, we have to assume a time rate of change of velocity. The classical assumptions in this respect have given results differing radically from actual experience. This will be discussed in more detail later.

Second, we have to assume that cavitation conditions on a self-propelled model are the same as those on a ship. This assumption is, of course, known to be erroneous. To produce comparable cavitation conditions we have to run the model propeller alone in the variable pressure water tunnel, and that is not large enough to hold the model hull too. Although during reversal the ship and the propeller are not both stopped at the same time, yet near the time of reversal one or both are moving very slowly. Under such conditions, as Commander Gold points out and shows, there is little cavitation to be expected in theory or in practice. But during other periods of the backing process, cavitation of exceptional violence occurs as may be seen in photographs presented by Commander Dodson. (1)*

Third, we have to assume that the wake fraction at any instantaneous speed during accelerated motion is the same as that at corresponding speeds of steady motion. It is almost impossible for this to be true. Suppose, for the sake of example, that at a series of steady speeds the wake fraction is the same for each speed. A long column of water is moving in the wake at some definite fraction of the ship's steady speed. Now accelerate the ship relative to that wake. Could the wake fraction possibly remain the same? Notice the violent turbulence and air bubbles in Commander Gold's illustrations. Further research is indicated.

* Numbers in parentheses refer to bibliography at the end of this discussion.

Fourth, we have to assume that the phenomenon of virtual mass (or virtual inertia) is non-existent in the case of ships. This assumption is not correct, although the effect of virtual mass may be small in this case. When a body is accelerated in a fluid, the effect is as though the mass of the body were increased by a mass equivalent to k times the mass of the fluid displaced by the body. The value of k depends upon a number of factors, among which are the rate of acceleration, the kinematic viscosity of the fluid, the form and dimensions of the body. In some cases k is as great as 1.0; and for spheres is generally greater than ½. A résumé of this subject, together with a copious bibliography, is given by Bateman (2). Very little work has been done to determine the value of k for ships, but a little has been done. Conn (3) mentions that Froude's "experiment with the *Greyhound* showed that the total mass of the ship plus the entrained water amounted to from 1.16 to 1.20 times the ship displacement." In other words, k was about 16 to 20 per cent. In model basin experiments, Kempf (4) found about 5 per cent. Kempf and Helm (5) give still more details in another paper. While our knowledge of the virtual mass associated with a ship being accelerated ahead or astern is unsatisfactory, nevertheless the amount of such virtual mass is still too great to be ignored. Further research in this respect is indicated.

Commander Gold, by using a real ship, has eliminated the effects of all of these assumptions, except the effect of virtual mass on thrust. That also would have been eliminated if he had had a thrust meter which could have operated a cathode ray oscillograph. Lacking such an instrument, he was forced to estimate the thrust by taking "the difference between the total force on '$M \frac{dV}{dt}$' curve and the 'R' values." Such a procedure is always unsatisfactory, though sometimes it is the best available.

His ship experiments were not the only recent ones, of course. For example, Commander Curry (6) presented actual data from two Coast Guard Cutters, and although he was handicapped by very inadequate instruments, he produced valuable results. Commander Dodson (7) also presented ship data, and though he did not describe his instruments or methods, they were of the same

general nature, although not quite so well developed as those of Commander Gold. How greatly these actual ship experiments aid in banishing a bugaboo of engine designers will appear in the subsequent discussion.

This bugaboo is presented forcefully in an excellent paper by Mr. W. E. Thau (8). In going from full RPM. ahead to zero RPM., certain theoretical considerations lead to the assumption that there will be a tremendous hump or peak of negative torque, much greater than the torque at zero RPM.; and that this will make the design of backing machinery very difficult. In his Figure 1, Mr. Thau presents two speed-RPM. curves, A and B, showing this theoretical hump. His theoretical curves are reproduced in Figure 1 of this discussion with corresponding curves from the actual ship experiments of Commanders Gold and Dodson, superimposed to show how radically they differ. *There is no hump in these actual ship curves.*

The fear of this hump probably arose because careful enough attention was not given to the classic paper of 1916 by Lieutenant (now Rear Admiral) S. M. Robinson (9). In that paper he showed that *under certain specific assumptions,* there would be a "hump in the torque curve." The principal assumption leading to this prediction may be stated as follows:—*The ship maintains constant full speed ahead until the propeller completes its reversal to full RPM. astern;* then the ship slows and backs while the propeller maintains constant RPM. astern.

That assumption gives, of course, a limiting case which can be approached but never reached. With true scientific accuracy, Lieutenant Robinson was careful to draw attention again and again to this assumption of constant ship speed during propeller reversal. For example, the following are quotations from the pages indicated in his paper (9):

"*With the ship speed constant,* the torque of the propeller, as its revolutions per minute are reduced, passes through a high maximum torque before it reaches zero RPM. In other words, it requires a greater torque to bring the screw to rest than it does to hold it at rest." (pp. 68-69.)

"*The ship is assumed to be making a constant speed ahead* at all points on this curve." (p. 70.)

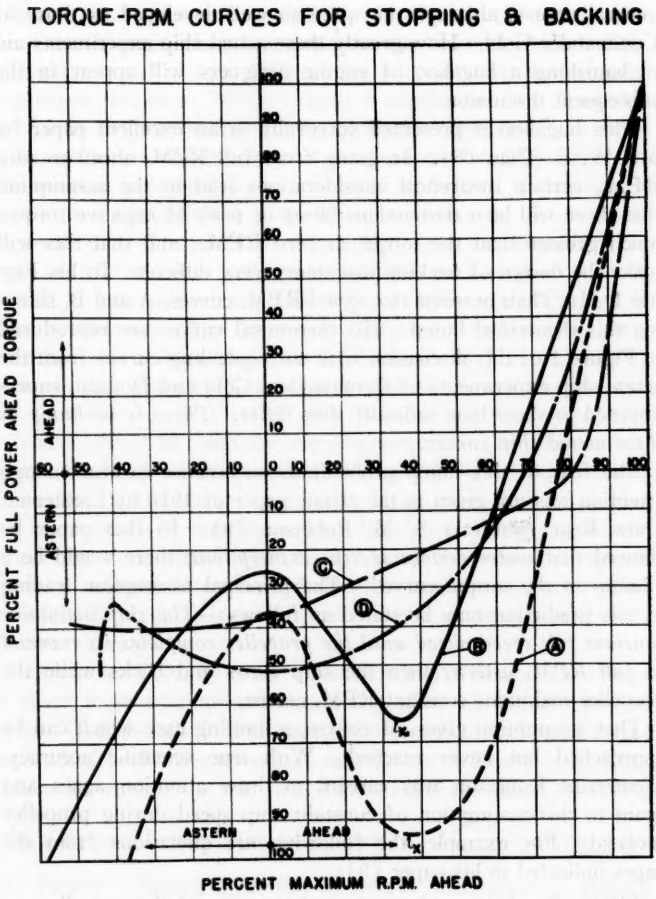

FIGURE 1.

Curves "A" and "B" are theoretical and assumed torque curves from Mr. Thau's paper.

Points "X" and "X_1" on the above curves are the theoretical humps of astern torque before propeller stops.

Curve "C" is actual torque curve from ship data on Figure 11 of Comdr. Gold's paper and curve "D" is actual torque curve from ship data on Figure 17 of Comdr. Dodson's discussion.

There is no trace of the theoretical hump in these data from actual ship performance.

And then referring to his actual ship experiments, he was very careful to show that ". . . by means of the deceleration curves . . . *all points were reduced to the same speed.*" (p. 72.)

(Note: Italics in above quotations are mine. L. P. S.)

In the absence of adequate instruments to record instantaneous transient phenomena during backing, some assumptions had to be made as to how propeller RPM. varied with ship speed during reversals. The assumption of the limiting case as made above was reasonable because it indicated the worst theoretical conditions which could be assumed, and if we designed for that we were safe for anything. This is analogous to our assuming, for preliminary investigations, the limiting but physically impossible case of isentropic expansion of steam, which gives the best theoretical conditions.

But with the advent of adequate instrumentation we can determine how propellers on ships really behave. For example, we can refer to Commander Gold's Figure 11 and plot the propeller RPM. against ship's speed from full ahead to maximum astern. This has been done in Figure 2 of this discussion, and results in the curve A-B. Obviously there are an infinite number of possible curves between point A (ahead) and point B (back). The classical assumption was the limiting case of the right angled curve A-C-B.

It was this latter *assumption* which gave the fearsome "humps" which have frightened many engine designers. An assumption more closely approximating ship performance was made by Conn (3), and for a model test gave a trivial "hump." He interpreted the phenomenon correctly by saying, "The peaks in the torque curve depend, naturally, on the *assumed variation of speed and RPM.*, but no full-scale data regarding the latter are available to the Author." In a real reversal test in the Hamburg tank when the propeller was forced to reverse in 4.5 seconds, Kempf (4) shows evidence of a "hump" in the torque curve so very slight that it is hardly more than a vibration.

But with adequate instrumentation, and reporting what actually happened on actual ships, neither Commander Gold nor Commander Dodson show any trace whatsoever of the hump. Their data indicate just this: The theoretical hump cannot appear in

practice unless we have so much available excess torque, and the ability to apply it so quickly, that we can force the propeller into exceptional conditions. If we do have those two abilities available, we need not fear the hump. If we do not have them available, we will not meet the hump for the propeller will, of necessity, take some milder path across the speed-RPM. plane, as from A to B in Figure 2.

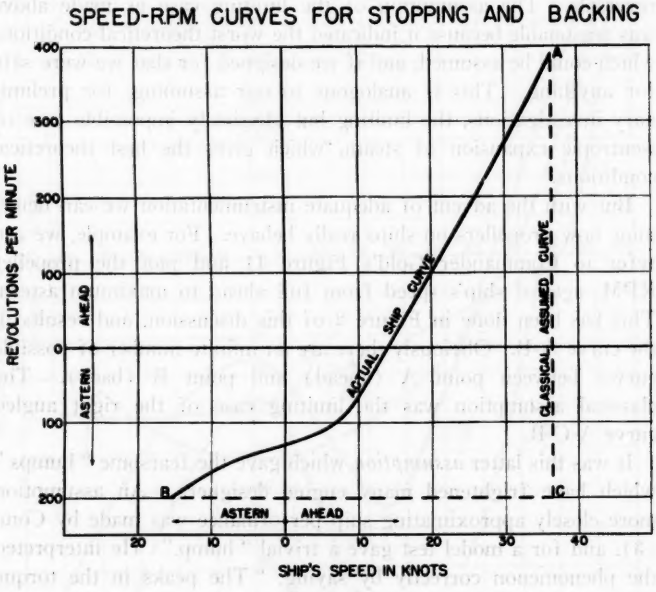

FIGURE 2.

The "actual ship curve" A-B, is drawn from data in Comdr. Gold's Figure 11.

The "classical assumed curve" A-C-B, predicts the theoretical hump shown in Mr. Thau's paper.

There are an infinite number of possible curves from A to B. If "speed of advance" were substituted for "ship speed" it would merely change the scale of abscissas.

Owing to the tremendous backing power of our electric drive battleships, it is quite probable that we might be able to run them into the torque "hump" to some extent. It is hoped that Com-

mander Gold can repeat his careful experimental observations on one of those battleships, as the additional data would be invaluable for design purposes.

When he performs similar stopping and backing tests on other ships, it is hoped that he will have as additional instruments not only a recording thrust meter and an instantaneous velocity recorder, but also have instruments for recording transient steam pressures, temperatures and vacuum, in addition to the electrical data for generators and motors of electric drive ships.

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ELECTRICAL INSULATION.

By Jesse B. Lunsford, Member.*

The author presents the fifth and last part of his series. One part was published in each issue of the Journal *during 1940.*

PART V—LIGHT WEIGHT ELECTRICAL MACHINERY.

OBJECTIVE PHILOSOPHY.

As stated repeatedly, and in several minor variations hereinbefore, there is not only a definite objective to this series of discussions; there is also a definite philosophy in line with it and a concrete plan of action back of it.

In this connection the author is reminded of a friend who, being somewhat of a skeptic, and also a believer in the theorem of least work, insists that it is unnecessary to start any action until there is a good answer to three *whys*. These three *whys* are, in their fixed order (and even their order is important):

(1) *Why* do *any*thing?

(2) *Why* do *this* thing?

(3) *Why* do it *now?*

If everything is under control, or if it is not absolutely clear that anything needs to be done, *why do anything?* Even if everything is not as it should be—unless there is some urgent reason for change and/or one is actually looking for work, *why do anything?* In short, one may be able to save himself much work and bother, and avoid the next two questions entirely if he will but insist upon a convincing answer to the first question.

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Assuming, however, that one is unable to escape from the first *why,* there are still two more of them; and the second one offers a very fine opportunity for an alibi. With one authority advising one thing and another suggesting something else; with every diagnostician shouting a different disease and no two doctors in agreement as to a cure; why do *any one* particular thing? In short, "*why do this thing*" instead of following up one of the many *other* ideas advanced? This is usually a very good place where one can, in all conscience stop, and go no further.

Finally, if even the best of urges has not been fully satiated, disillusioned, or otherwise exhausted by now, one arrives at the third question. And, since the urge to "put off" is the strongest one we have to face, one is indeed looking for trouble when he really insists that there is a good and sufficient answer to the last question of "*why do it now?*"

Doubt it if you must, but the author has gone all through this routine—and is more than ever convinced, (1) that *something* should *be done,* (2) that *this* is the thing to do, and (3) that it should be done *now.* In Parts I to IV, inclusive, of this series he has endeavored to convince others of the same thing because *this* thing can only be done *now,* if all hands believe in it and will work together to that end.

A GENERAL SURVEY.

Assuming then that a general interest in this work does exist, and that the principal question which now remains is exactly *how* all may contribute their bit to this end, let us look behind the scenes and observe what goes on. It may be that a brief explanation of some naval needs and practices will contribute to this understanding.

In order the better to visualize the problem of light weight electrical machinery from the standpoint of United States naval needs, suppose we break the subject down into the following categories:

(*a*) Service Needs (standardized expression of these needs).
(*b*) Material Standards (materials suitable to those needs).
(*c*) Process Standards (processes suitable to those needs).

(*d*) Electrical Clearance and Creepage Standards (minimum suitable).

(*e*) Design Standards—New Naval Bases.

(*f*) Test Standards.

SERVICE NEEDS.

In stating these needs, it might be easier to point out that the *normal* service operation of electrical machinery aboardship imposes conditions of unusual *severity* in comparison with those ordinarily met with in somewhat similar installations ashore. It might, therefore, be well to outline these conditions so that the reader may be better able to draw his own conclusions. Suppose we think of these in the following terms:

(*a*) Moisture
(*b*) Heat
(*c*) Shock and vibration
(*d*) Weight and space
(*e*) Other factors.

(*a*) *Moisture.*—Little thought on the subject will be necessary to convince anyone that the materials used and their method of application must be such as to insure the satisfactory operation of electrical machinery in an atmosphere which is normally laden with moisture (even fog and fine wind-blown droplets of water, not just humidity alone), and where occasional drip, spray, or flooding is to be expected even in the best of ships and under the best of conditions.

The component materials selected for use as electrical insulation must, therefore, comprise those which exhibit the lowest relative water absorption and/or the least deleterious effect of water on their dielectric properties consistent with the other necessary characteristics. So, in the combinations of such materials for a given design of machinery or equipment, every precaution must be taken against the possible failure of such composite insulation due to the combined effect of moisture and of the several other factors enumerated hereinunder.

(*b*) *Heat.*—The high ambient temperatures existing within a vessel's machinery spaces (assumed to be 50 degrees C.; 122 degrees F., but often higher), plus the specified maximum permissible temperature rises; together with the ever present moisture referred to in the foregoing, constitute what are commonly referred to as "tropical service conditions." The composite insulation should possess, under such conditions, the highest relative "*longevity*" practicable and consistent with the other necessary properties.

(*c*) *Shock and Vibration.*—The insulation should possess "toughness" to the greatest degree compatible with the other required characteristics which are inherently in opposition. By this is meant not only the initial ability to bend or flex before rupture, but even more particularly the maintenance of such initial flexibility (longevity) throughout a long period of subjection to the heat and moisture conditions enumerated above. Where the necessary heat and/or moisture resistance cannot be attained with the required toughness, the mounting of such insulation should be such as will preclude any strain due to vibration and shock.

(*d*) *Weight and Space Required.*—To anyone who has ever been aboard a modern man-of-war it seems hardly necessary to emphasize the point that the space is so crowded as to justify every effort at "squeezing" machinery and equipment just as much as possible and still have it work unfailingly. As to weight, it seems almost too obvious to mention that every pound of weight saved on machinery and similar equipment is just another pound which can be added to the *fuel*, the *armor*, or the *ammunition* and *guns* which may be carried. And since the "size" of a warship is measured in terms of its hitting power or steaming radius, it goes without saying that the smaller the machinery the bigger, in effect, the ship could be.

(*e*) *Other Factors.*—While the foregoing covers those specific factors which are ever present for practically all applications, there are others such as oil, sea water, acid, etc., which apply only to certain classes of equipment and/or to certain conditions which must be specified for the particular application. In all such cases the added factors have to be taken into consideration in the par-

ticular designs involved, and the choice of materials and methods of insulating against such conditions must be subject to the approval of the bureau concerned.

MATERIAL STANDARDS.

Having briefly surveyed the service needs, it is now advisable to survey the field of materials which are now, or which may become, available to meet those needs. There is so much advertising and sales hocum concerning electrical insulating materials that there has to be some unbiased and commonly accepted means of evaluating their qualities. This problem is almost analogous to that faced by the small boy who is required to add up a lot of fractions. He is puzzled as to how to add up 1/5, 1/3, and 1/7, etc., until he learns at least something about "least common denominators." When he learns to *convert* each of the several fractions into a usable product, by resorting to such an *evaluation,* the problem of addition becomes much simpler.

And so it is with electrical insulating materials. One manufacturer claims certain values by one method of test or on the basis of certain factors which he emphasizes and which another poohpoohs. Before even an insulation engineer can add up all these highly diverse fractions he must have some "common denominator." It is not easy to arrive at such common denominators in the light of all the advertising and selling that goes on.

In the United States Navy specifications there is at least a careful effort being made to lay the groundwork for what are intended to be some *"common denominators."* These are not perfect, but, given time and unbiased direction, they can be as near an approach to such ideals as any other set of standards in existence; and at least they have the advantage of striking a mean somewhere between what a manufacturer thinks of his own product and what his competitor thinks of it. They will, therefore, be considered in that light in the following discussion; as a *means to an end* rather than as an end in themselves.

The performance values shown in the applicable Navy Department specifications for various types and classes of electrical insulation are based upon the minimum characteristics which can

be considered as meeting the naval needs expressed hereinbefore. In general, therefore, the minimum standards thus set are to be considered as values which must be strictly adhered to if service reliability is to be maintained. It is obvious, of course, that there are 1000 and 1 differing machinery designs; and that the equally large number of different insulation set-ups may require a large number of minor variations for the best effect. In short, while the number of individual designs may be almost infinite, the number of naval standards set up for quality must be *finite* for administrative purposes. That is to say, the naval standards must be based on *classes of products* to meet *classified* service *needs*, rather than on *individual* circumstances. Thus, in actual practice it may sometimes be necessary, and even desirable, to depart slightly from naval standards in specific instances; but these departures should form the exceptions and not the rule.

In order not to limit the machinery manufacturers' initiative, the specifications do permit the designer to utilize a non-standard material or non-standard combination provided that

(*a*) There are no Navy standard types or classes of materials strictly applicable to the specific purpose, or,

(*b*) If a Navy standard type or class of insulation is applicable, there is a distinct advantage in the use of a material somewhat at variance therewith when viewed from the standpoint of the particular design. In the latter case, however, it shall be demonstrated that there are no important offsetting disadvantages in such use; and, further, that in the event of failure in service, satisfactory repairs can be made by the use of Navy standard materials.

There is a still further matter to be considered in connection with naval standards for materials in order that they may not act as a drag upon individual initiative. The purchase specifications for insulating materials cover certain features which, while essential from the standpoint of naval stocks and/or the naval facilities for fabrication or application, need not apply to the manufacturers of electrical machinery or equipment in their own utilization of the same types and classes of materials. For example, such features as the thickness, length, and width of sheet or tape insulation; the dimensions of rods, tubes and shapes of molded or pressed insulation; and the flashpoint, drying, or baking time, working viscosity,

consistency, etc., of liquid or plastic insulation. These may all be essential features where direct purchases of insulation are made by the Navy, and the materials are to be carried in stock by the Navy; but they are of no consequence to the Navy when the same materials are applied by the machinery or equipment manufacturer.

Thus, in the application of the referenced Navy Department specifications to the manufacturers' own designs of machinery and equipment, only the *performance* values of the naval *standards* need be considered. For example, insulation resistance, dielectric strength, heat resistance, moisture absorption, aging, tensile strength, flexural strength, compressive strength, impact strength, etc.

The foregoing would seem to state such obvious truths as to require no explanation. It is a fact, however, that such explanations, assurances, and reassurances are almost daily necessities. They are being repeated here because a full understanding of naval needs and situations is so vitally necessary in the attainment of completely cooperative effort. It does matter greatly, if our final objectives are to be achieved by concerted effort, that everyone should have a knowledge of and faith in naval *standards* as an essential means to *progress* rather than as just another bar to it.

THE OLDER STANDARDS.

The following list of Navy Department specifications is given as an illustration of certain *older classes* of electrical insulating materials already covered by *standards*. These standards are in print and available for general distribution. Most of the classes of insulation listed here are old, i.e., they have met the test of years of service and are not to be confused with a number of newer ones now in the course of preparation. They are listed, with a brief notation as to their general service applications, not because of any great bearing upon the primary objective of this series (light weight electrical machinery), but rather to lend completeness to the discussion; i.e., it shows the place from which we start.

17C8. Cambric, insulating, varnished.
17F5. Fiber, insulating, gray.
17-I-6. Insulation, electrical, asbestos board, impregnated.
17-I-9. Insulation, electrical, paper, asbestos.
17-I-10. Insulation, electrical, paper, pressboard.
17-I-11. Insulation, electrical, paper, fish.
17-I-13. Insulation, electrical, slot-cell, composite, armature.
17M5. Mica and pressed mica plate.
17S10. Sleeving, insulating, cotton.
17T1. Tape, insulating, rubber.
17T6. Tape, friction.
17T14. Tape, insulating, asbestos.
17T15. Tape, insulating, linen-finish, plain.
17T16. Tape, insulating silk.
52A7. Asphalt, battery sealing.
52V13. Varnish, insulating, for electrical purposes.

The conditions of their several uses are so varied that there is no one material which is best suited to all purposes. In fact, the very best material for one purpose may be and often is absolutely the worst one which could have been picked for another application. In order to assist in the proper application of the various materials the following notes were prepared several years ago to show the limitations of each of the older materials:

17C8. Cambric, insulating, varnished.—This material is furnished in the form of *cloth* and also as a *tape* in various widths. Varnished cambric is one of the best general purpose insulations, because of its high dielectric strength, its flexibility, and its resistance to moisture, oil, etc. Slot cells, coil wrappers, jackets, liners, etc., may be cut to the desired shape and size from the cloth. The tape is intended for use in insulating bus bars, cables, machinery leads, the curved portions of armature, field and stator coils and for general splicing purposes.

17F5. Fiber, insulating, gray.—Fiber is one of the earliest and most abused of insulating materials. Its physical characteristics, particularly its extreme toughness, its high dielectric strength and its ready availability make its use almost indispensable for certain applications such as liners, spacers, bushings, slot cells, etc. The readiness with which it absorbs moisture and its tendency to

change shape under heat, however, necessitate certain precautions in its use if it is to be successfully employed. An impervious coating of varnish will prevent the absorption of moisture, and suitable design means may be employed to insure its retention in place under changing heat conditions.

17-I-6. Insulation, electrical, asbestos board, impregnated.—Wood was the first material employed for switchboards. Slate came next, but was soon discarded in the naval service because of its tendency to crack under shock; also the inclusion of hidden metallic veins made it a very doubtful dielectric. Specifications 17-I-6 cover the present material for this purpose, which is referred to on Navy drawings as type A material. While type A material is intended for use primarily as a switchboard and panel material, there are certain instances (Navy standard drawings) where its use is specified or permitted for insulating forms, bases, and strips of a simple character; other applications should have the specific approval of the bureau concerned. Such insulating forms, bases, and strips should be suitably finished on all surfaces and accessible raw edges.

17-I-9. Insulation, electrical, paper, asbestos.—This material is furnished in two types, viz.: Type U (untreated), type T (treated). Type U (untreated) asbestos paper is intended for use as a flame-resisting wrapper for cables and conductors, as a lining for controller inclosures (vicinity of arcs, etc.), and as a separator between turns of field coils, etc., of machinery designed for high temperatures. Type T (treated) asbestos paper is intended for use as a heat-resisting, moisture-proof insulation in field and armature coils and in the preparation of cores or spools for the winding of magnet coils.

17-I-10. Insulation, electrical, paper, pressboard.—This material is furnished in but one type, in several thicknesses, and is intended for use where a dense, flexible, easily worked material of good dielectric strength is required. More specifically, it is intended for use as layer insulation and spacers for various types of coils, and for collars, shields, sleeves, cells, etc., where it is necessary to have a material combining good insulating value with molding ability and mechanical rigidity.

17-I-11. Insulation, electrical, paper, fish.—Fish paper (sometimes referred to as rawhide fiber) is intended for use as electrical insulation where an extremely tough, strong, dense paper is required. More specifically, it is intended for use as slot lining or coil jacketing, and for similar applications where space limitations require the maximum resistance to mechanical abrasion per mil of thickness, coupled with good insulating value and resistance to heat. It is intended to replace pressboard where a thinner, tougher, and more flexible insulation is required. It is intended to replace horn fiber where a smoother finish and greater resistance to heat and to mechanical injury by bending, creasing, and abrasion is required.

17-I-13. Insulation, electrical, slot-cell, composite, armature.—Composite insulation of this type is intended primarily as a lining for armature and stator slots in electrical machinery. It combines the advantages of varnished cambric (17C8) and fish paper (17-I-11) in a single material which promotes time saving, slot-space conservation, and a neater appearing job. While it does not cover the range of applications afforded by either of its component materials, it is a more desirable one than either where it is practicable to employ it.

17M5. Mica and pressed mica plate.—Mica is the old reliable. Where it can be successfully employed there is nothing better. There are, however, some applications for which it can not successfully be applied, others in which even if it could be applied it would be inferior to certain other materials, and still other places where its use could not be justified in view of its high cost. It is highly heat resistant, but lubricating oil, grease, etc., is a deadly enemy. Its principal uses are as sleeves, collars, washers, etc., for apparatus exposed to considerable heat; as commutator and slip-ring insulation for all types and sizes of electrical machines; and as coil insulation in the case of machinery designed for high temperatures or high voltages. Wherever it is applied it must be retained in compression, in a direction normal to its laminations, in such manner that it can not shatter and (except for the insulation between commutator bars, where it is impracticable to do so) be thoroughly protected against oil, moisture, and collection of dirt. Unless these precautions are taken, it is better to use another type of insulating material.

17S10. Sleeving, insulating, cotton.—The principal use of cotton sleeving is in connection with the winding or repair of armatures and stators. A suitable length of sleeving, of the correct diameter, is applied to each lead to the commutator bars. Sleeving is provided in a variety of sizes (diameters) and in several colors, so that the circuits can be easily distinguished and correctly connected. Sleeving may also be profitably employed in insulating short connections such as frequently occur in apparatus subassemblies.

17T1. Tape, insulating, rubber.—The principal use of rubber tape is as a repair or splicing material for rubber-insulated cables and joints. It lacks the necessary physical properties for a complete insulation and must be supplemented by others which can furnish proper support.

17T6. Tape, friction.—Contrary to popular belief, friction tape is not an insulating medium and was never intended to be. It is used for much the same purpose that a surgeon uses adhesive tape, as a temporary binder to hold other materials in place. Specifically, friction tape is used as a binder over rubber tape (17T1), varnished cambric (17C8), linen tape (17T15), and various other fabric or paper insulations. Its use for such purposes may be temporary or permanent, but in any event it is used because it is strong and sticky. It should not be depended upon as an insulation.

17T14. Tape, insulating, asbestos.

17T15. Tape, insulating, linen-finish, plain.

17T16. Tape, insulating, silk.

These tapes are intended to be used as the outer insulating fabric covering of electrical windings of every description. They furnish one of the mainstays in the insulation of such windings. They are also used for splices and joints in machinery leads, cables, and for the insulation of bus bars, heavy connections, etc. The tapes are physically strong and are absorbent, so that they will take up insulating varnishes or other impregnating medium used to assure the imperviousness of the completed windings to dust, water, oil, acids, alkalies, or other deteriorating influences. Asbestos tape is used when the machinery is designed for high

operating temperatures, and linen-finish or silk tape for machines operating at the lower or usual temperatures. Silk tape is used where space does not permit linen-finish tape to be used, such as in instruments and small devices where space is at a great premium. It is a matter of judgment, based upon temperature, space, and cost, which of these three tapes should be employed in the individual case.

52A7. Asphalt, battery sealing.—This compound is intended for use in sealing storage-battery covers and parts. It adheres to hard rubber and glass and contains nothing soluble in the electrolyte or injurious to battery plates.

52V13. Varnish, insulating, for electrical purposes.—Five grades of varnish are provided, viz.: BA, BB, CA, CB, and CF. The first two grades are black in color and the last three are clear. These two colors are provided to meet the preferences of the individual user. These specifications are based upon the data accumulated as the result of over 600 very complete laboratory tests, covering most of the brands of varnish which are commercially available. The uses of these varnishes may be described as follows:

Air-drying varnishes, grades BA and CA, are intended for use on armature coils, field coils, and other electrical windings where a good, fairly flexible, oil and moisture-proof insulating varnish is required, but where the lack of proper facilities would preclude the use of a baking varnish.

Baking varnishes, grades BB and CB, are intended for use on armature coils, field coils, and other electrical windings where the service conditions are such as to require the maximum of protection that the best insulating varnish can afford. Wherever the existing facilities will permit, one of the baking varnishes specified (grades BB or CB) should always be used in preference to any of the other grades, as a first coat at least.

The finishing varnish (grade CF) is intended for use as a final coat, to furnish additional acid resistance, and, by smoothing up the rough surfaces, to decrease the tendency of dirt to lodge thereon. The hard, glossy surface not only enhances the general appearance, but it enables the windings to be more easily cleaned.

Note.—As a black paint for battery trays, cables, connection boxes, and similar electrical fittings a good grade of asphaltum varnish, such as is covered by Navy Department Specifications 52V1 (varnish, asphalt) of latest issue is suitable. When purchased for such use, however, it should be definitely stated that the varnish is to be used for this purpose and that it must be resistant to mineral acids. (This grade of varnish should never be used as an insulating varnish for electrical windings.)

THE NEWER STANDARDS.

There is another and a newer series of standards now in the making. Some of these represent developments arising out of the old, whereas others portend a radical departure therefrom; but all of them have as their central theme the ideas and philosophy expressed in Parts I to IV, inclusive, of this series. Through all of these there runs the ideology that no one existing class of insulation is sufficient unto itself alone, at least for naval shipboard applications, and that, therefore, the most practical solution lies in the pooling of the strengths of several insulations in combination so as to minimize their separate and inherent weaknesses.

In short, and in line with the old adage of the "blind" walking and carrying the "lame"—until we can work out a single insulator that can both *see* and *walk*, we had better team them up so that we can use the eyes of the one to guide the footsteps of the other. Or, to express it still differently, we may use as our building lumber a "*ply-board*" made up from both the *carbon* and the *silicon* trees in our forests—maybe a little cross-pollinizing or other hybridizing means might also be worked out in time.

The following of the newer standards, of those which are being worked up, are listed hereunder for the purpose of showing a trend—a trend which we are hoping (and striving) to have culminate in light-weight electrical machinery.

17-I-15. Insulation, Electrical, Plastic-Sealer.

17-I-16. Insulation, Electrical, Liquid, Quick-Drying.

17-I-17. Insulation, Electrical, Synthetic-Resin Composition, Group AS (all synthetic).

17-I-29. Insulation, Electrical, Asbestos Fiber, Untreated (Group AFU).

17-I-30. Insulation, Electrical, Cotton Fiber, Untreated (Group CFU).

17-I-31. Insulation, Electrical, Glass Fiber, Untreated (Group GFU).

17-I-32. Insulation, Electrical, Mica (Group M).

17-I-33. Insulation, Electrical, Paper and Fiber, Untreated (Group PFU).

17-I-34. Insulation, Electrical, Silk Fiber, Untreated (SFU).

17-I-35. Insulation, Electrical, Asbestos Fiber — Synthetic Resin Insulation Combinations (Group AF-SRI).

17-I-36. Insulation, Electrical, Cotton Fiber—Synthetic Resin Insulation Combinations (Group CF-SRI).

17-I-37. Insulation, Electrical, Glass Fiber—Synthetic Resin Insulation Combinations (Group GF-SRI).

17-P-4. Phenolic Material, Molded.

17-P-5. Phenolic Material, Laminated.

17-P-8. Plastic, Synthetic-Resinous Material for Electrical, Illumination, and Light Transmission Applications.

For the most part, the above listed specifications are still in the *course* of *development* as standards. The majority are not even available for purchases as yet. Three notable exceptions to this are 17P4, 17P5, and 17-I-31. The first two (17P4 and 17P5) were the basis of Part III of this series, "Resins (Synthetic and Otherwise)," while the third one formed the central theme of "Part IV—Rocks (Synthetic and Otherwise)."

In every case, however, the newer specifications are being fashioned along *functional* lines rather than chemical compositions or by any of the older methods of *deifying* a particular *product* or *design*. The purpose back of this method of indicating "*service goals*" instead of "*manufacturing methods*" or "*sales arguments*" has been the central theme of this series (Parts I to V, inclusive).

There is, however, one further illustration of the working out of this philosophy which might be given. For example, take the following type designations quoted from 17-I-17:

"B-3. *Classes.*—With respect to the preeminent characteristics involved, this specification covers two general classes of material, viz.:

Class E—Electrical properties emphasized.

Class M—Mechanical properties emphasized.

"B-4. *Types.*—Based upon the general group (AS) and class (E and M) designation symbols, the material shall be furnished in the following types,* as required:

Type ASE-1, high dielectric, low losses
Type ASE-2, high dielectric
Type ASE-3, good dielectric
Type ASE-4, moderate dielectric
Type ASM-3, moderate mechanical
Type ASM-2, good mechanical
Type ASM-1, high mechanical

The very order of arrangement and the letter-numeral designation of the classes and types quoted above will serve to make clear how the general philosophy expressed in Parts I to V, inclusive, of this series is being executed. The listing shows two things, viz.:

(*a*) Since one property is achieved at the expense of another, the *functions* vary with the *degree of emphasis* placed upon a *class of application.* As the primary consideration shifts from *electrical* to *mechanical,* so does the *balance* of *properties* necessary to achieve the purpose.

(*b*) Where such shifting is taken into consideration from the beginning, a complete plan can be laid out so that a *few classes* can be selected to cover a *wide field*—in short, we start out with "*simplified practice,*" or what amounts to a "*preferred number system.*"

Actually, as laid out, the *basic* materials which, by chemical composition, might fall closest within the above listed functional groupings are, in their relative order of listing:

polystyrene
cellulose acetate
cellulose triacetate
Ethyl cellulose
co-polymer (vinyl chloride-vinyl acetate)
rubber hydrochloride
polyvinyl acetal
polyvinyl chloride

"*The first and the last of the types listed represent the extremes in service applications, the other types listed being graduations between, as the balance between characteristics in opposition is shifted."

No such mention of chemical compounds is, however, made in the specifications, because one could, by the use of the proper kind and amount of plasticizer take almost any one of the above basic materials and fit it into the proper *functional* role (ASE-1 to ASM-1, inclusive). Such an arrangement not only permits several raw material sources to pit their skill against each other, in the attainment of a common objective, but it also means lower prices because of competition and the spread of production facilities over a wider area in this country. It might be better, other things being equal, to have two small sources of basic materials located in widely separated geographic areas than to have twice their individual capacities, but only one basic source and that one located all in the same spot. And added to all these strategic advantages, we might gain the cooperation of the many added *minds* located in the different places with the different basic materials—and certainly *" added minds "* is not the least of the several considerations.

The foregoing is given merely to show that, in *developing standards* we *invite* criticism instead of *shying away* from it. Constructive criticism is essential to progress.

PROCESS STANDARDS.

General. As in the case with material standards, so it is with the processing of materials. There must be some common denominator by which the numerous processing methods may be defined and their proper spheres of usefulness outlined. The following process standards are now in force in the design of all types of electrical machinery standards for naval use. These will be modified and/or added to as rapidly as manufacturing knowledge and service experience dictate.

Electrical Windings All insulated electrical windings shall be thoroughly impregnated by a method which will insure the complete evacuation of all water and air from and the subsequent filling in, of all interstitial spaces within such windings. The liquid, semi-plastic or plastic insulation used for this purpose shall have such characteristics or be so applied as to insure thorough drying, solidification, or curing throughout the innermost recesses of the windings. Any failure to so cure shall be considered as evidence that either the compound selected or else the method of its application is in error and requires correction.

Methods of Impregnation. The following methods of impregnation, some of which are rather limited in their proper application, are recognized:

(*a*) Vacuum-pressure.
(*b*) Built-up.
(*c*) Centrifugal.
(*d*) Immersion.
(*e*) Pulsating pressure.
(*f*) Brushing and/or spraying.

The method to be employed may depend upon the given design and shall be as required or approved by the bureau concerned in the individual case.

(*a*) *Vacuum-pressure method.*—This shall be the preferred method where its use is practicable. It shall consist of an arrangement for heating the windings in a vacuum chamber, at the temperature and for the period of time necessary to provide for the complete evacuation of all entrapped moisture and air, and then, without breaking such vacuum, allow the liquid insulation (heated to the proper temperature) to flow into the windings under graduated pressure; followed by draining, baking, etc. In the application of this method it is essential that the evacuation of moisture and air be complete before admission of the insulation in the liquid state.

(*b*) *Built-up method.*—The specific details of this general method will necessarily vary with the particular design of winding involved. In essence, however, it shall consist of the impregnation and curing of the insulation at each step in the building up of the winding starting with the magnet wire. For economic reasons, this method is necessarily limited to coil design of such unusual size, shape and purpose as to warrant such special procedure. For technical reasons, the method shall be limited to such combinations of insulating materials and process methods as may be specifically approved by the bureau concerned in the individual case.

(*c*) *Centrifugal method.*—This method is a pressure impregnation method, the pressure being the effect of centrifugal force due to the rotation of the chamber containing the insulating varnish

and the windings to be impregnated. This method is also one of limited application, and its use shall be subject to the specific approval of the bureau concerned.

(*d*) *Immersion method.*—This method shall consist of first heating the windings to the temperature and for the period of time necessary to thoroughly dry them out, and then completely immersing the windings in insulating varnish for the period of time necessary for thorough penetration, followed by draining and baking. This procedure shall be repeated as often as necessary to fill in and seal over the interstices in the winding. This method is also one of limited application, and its use shall be subject to the specific approval of the bureau concerned.

(*e*) *Pulsating-pressure method.*—This method shall consist of repeated applications of pressure for suitable periods of time, interspersed with periods of zero pressure. The amount of pressure used and the time-duration of the pressure and rest periods may vary with the application, so the specific procedure used in the individual case shall be as approved by the bureau concerned.

(*f*) *Brushing and/or spraying.*—This is not considered to be an adequate method, in itself, of applying insulating varnish to electrical windings. Its use shall be limited to the first coat of varnish applied to windings previously impregnated, completely, by one of the other methods outlined above.

ELECTRICAL CLEARANCE AND CREEPAGE STANDARDS.

As in the case of insulating materials and processes, so it is important to arrive at some minimum acceptable standards relating to electrical *clearance* and *creepage* distances; otherwise, the whole aim may be thwarted by an unnecessary sacrifice of reliability in order to attain greater compactness and lighter weight. It is desirable to employ every engineering ingenuity to gain our purposes rather than to merley let down the bars on reliability—many others have tried the latter expedient, and it just will not work.

In order to arrive at some standards in this direction, a conference of leading manufacturers and naval technicians was called some years ago. As the service results to date, bearing upon the standards thus arrived at, have proven eminently satisfactory, a

brief outline will be given hereunder on the points discussed. It was agreed that the *principal* factors involved in this problem were:

(*a*) *Surface resistivity* of the type of insulation employed, particularly;

(1) Impregnated asbestos board (17-I-6).
(2) Phenolic (17-I-14 then, but now 17P4 and 17P5).
(3) All other types of insulation.

(*b*) Degree of exposure:
(1) Open.
(2) Partial enclosure.
(3) Dust-tight, or water-tight.

(*c*) Position:
(1) Overhead (top horizontal).
(2) Wall (vertical).
(3) Floor (bottom horizontal).

(*d*) Circuit voltage:
(1) Below 150 volts.
(2) 150 to 300 volts.
(3) 300 to 600 volts.

(*e*) Circuit application:
(1) Communication.
(2) Control.
(3) Lighting and power:
Below 150 KVA.
Above 150 KVA.

(*f*) Non-arcing live parts:
(1) Rotating, or with some movement.
(2) Semi-rigid.
(3) Rigid (stationary, no give).

(*g*) Arc rupturing parts:
(1) In direction of blow-out, if any.
(2) Vertical distance above contacts, where no blow-outs.
(3) Horizontal distance from and/or below contacts.

Discussion of the foregoing brought out the view that there were still other factors which influenced the situation and which must necessarily be given full consideration in the many applications involved. In order, however, to accomplish anything in the limited time available for the conference, it was necessary to limit the scope very materially. Specifically, it was necessary to limit it to a consideration of the following factors:

(*a*) rigid construction

(*b*) 125 volts/250 volts/500 volts

(*c*) open/enclosed

(*d*) top connected/bottom and side connected

(*e*) ebony asbestos/phenolic insulation.

The minimum value to be shown as to ground, and to opposite polarity, through air, and as creep over insulation, respectively.

During the discussion the following features were emphasized:

(*a*) The values agreed to were, in many cases, considerably below the standard design practices of manufacturers represented at the conference; and, probably, also of others. These manufacturers agreed, however, not to take advantage of this fact and lower their own standards unless it appears absolutely necessary for them to do so to meet Navy space and weight limitations.

(*b*) As the tentative values set represented an attempt to harmonize the wide divergencies in past practice, the net effect is an elevation of certain standards and a lowering of others, as judged by past naval practice. Where the tentative values set represent a rise in standards they will be strictly adhered to in every case. Where they can be interpreted as representing a lowering of standards, the Navy will not only not insist upon a lowering but will resist any general effort to do so. The lower standards will only be permitted where no other satisfactory alternative appears to be practicable.

(*c*) It is to be emphasized that the tentative values are not set up as a guide to aim for, but rather as the ultimate limit beyond which the Navy will not go under any circumstances. If it later develops that there is any general tendency to misconstrue the

purpose of these tentative limits, to secure an unfair economic advantage, with resultant unjustified lowering of technical standards, it may be necessary to revise them.

(*d*) These limits are to be applied to rigid construction only. Where rotating parts are involved, or where there is any question of rigidity, these limits must be increased; the exact increase to be based upon a consideration of the factors involved in the individual case. Neither do these values have anything to do with arc-rupturing contacts nor with any other factors not specifically covered by the three tables herewith.

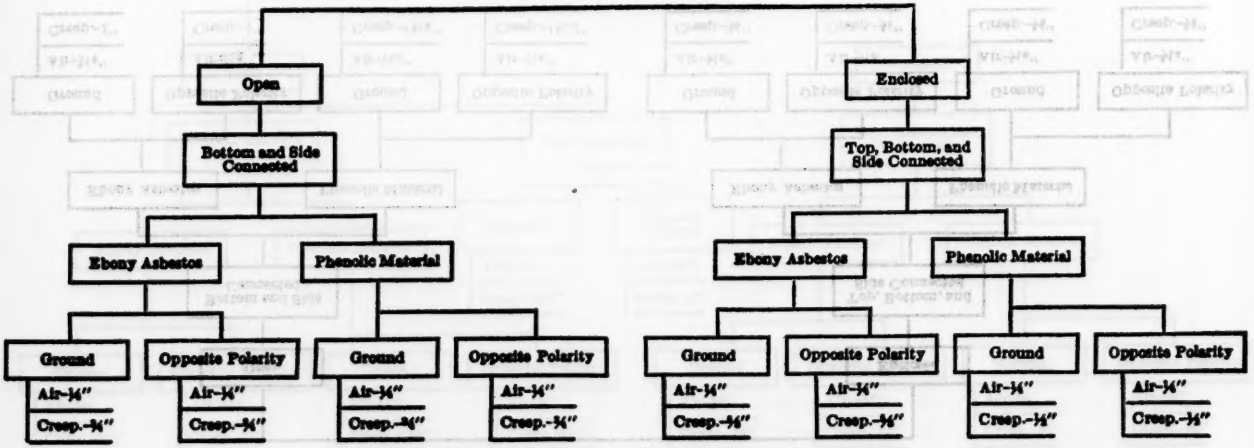
(*e*) These limits will not apply to certain electrical equipments which are otherwise definitely covered by Navy Department specifications unless those specifications contain no corresponding requirements or unless the corresponding requirements are of a lower order; in which case they will be revised so as to require the same or a higher value than is here tentatively set forth. It is the intent to continue to consider such equipments on the basis of their respective merits. While the limits will never be lower than is set forth herein, they may be specified of a higher value where the circumstances warrant. Here again it is the intent to utilize the tentative values where none now exist, and to elevate any which may be lower, but not to conflict with the specific requirements of any Navy Department specification where a higher standard is practicable and/or necessary.

Based upon the foregoing considerations, the following requirements were adopted as standard and are now shown in several Navy Department specifications:

"*Insulation Distances.*—The distance between nonarcing, uninsulated live parts to ground or to nonarcing uninsulated live parts of opposite polarity shall be not less than that shown in Tables I, II, and III. It is to be emphasized that the values shown in these tables represent the minimum acceptable limits for nonarcing rigid construction, that they apply to equipment rated at 200 horsepower and below, that they only take into consideration the average degrees of enclosure and service exposure, and that they cover only two classes of electrical insulation. Where such uninsulated live parts are arc-rupturing, or where there is any ques-

TABLE I

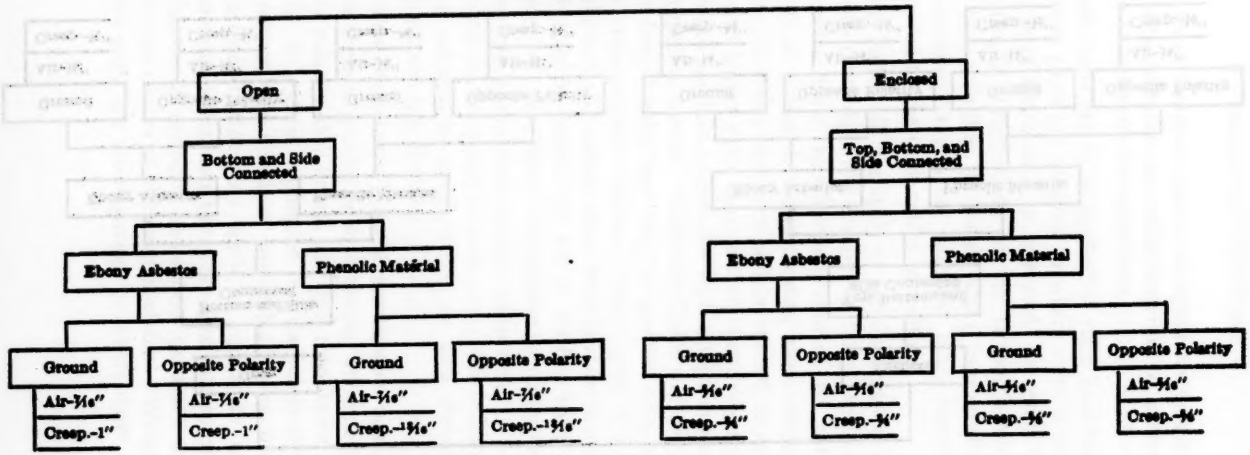
125 VOLTS A. C. OR D. C.



Clearances are absolute minimum and shall be increased where feasible.
Clearances are for 150 kva and below; increase clearances by 25 percent for above 150 kva.
Clearances are for rigid construction.

TABLE II

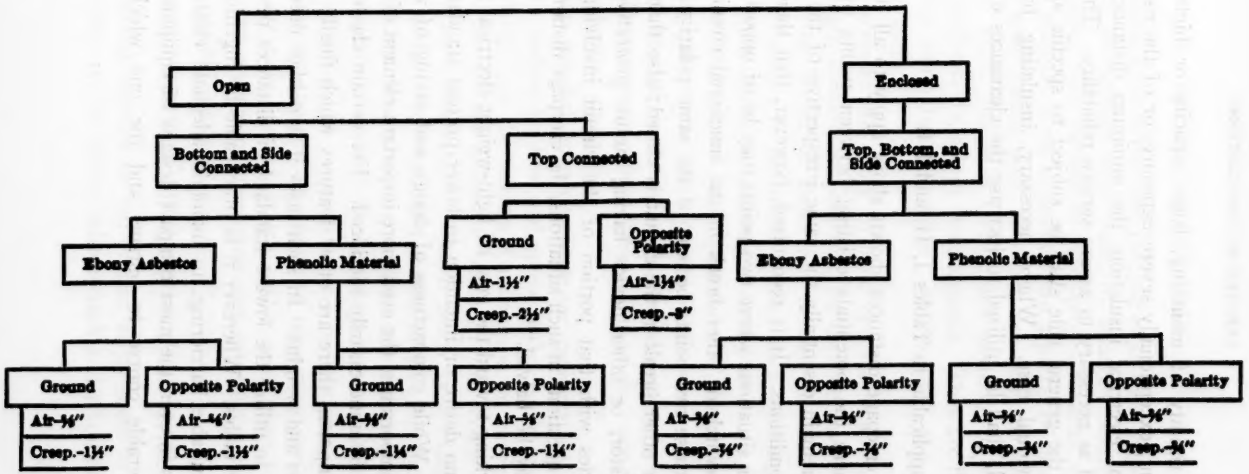
250 VOLTS A. C. OR D. C.



Clearances are absolute minimum and shall be increased where feasible.
Clearances are for 150 kva and below; increase clearances by 25 percent for above 150 kva.
Clearances are for rigid construction.

TABLE III

600 VOLTS A. C.



Clearances are absolute minimum and shall be increased where feasible.
Clearances are for 150 kva and below; increase clearances by 25 percent for above 150 kva.
Clearances are for rigid construction.

tion of rigidity of mounting, large capacity or higher voltage equipment, exceptionally severe exposure, or of the use of other classes of electrical insulation, the minimum distances shall be increased as necessary to assure service reliability. These exceptions to the general rule shall be subject to specific approval in the individual case. Where necessary, insulating barriers, as approved, shall be utilized to increase the clearances or creepage distances."

Note applicable to Tables I, II, and III.

"The creepage distances shown above apply to all those situations where the potentials existing between points of different polarity remain essentially the same irrespective of the operating circuit conditions. It is recognized, however, that there are certain other situations where two points may be of opposite polarity when a switch or other break in the functional circuit is open, and yet these two points become of the same polarity when this switch or other break in the circuit is closed; also that a voltage coil, resistor, or other device having circuit protective capacity is in series with that portion of the circuit involving the two points in question; in such situations, the creepage distances shown above may be halved."

In working toward the goal of light-weight electrical machinery there is no desire or intention to lower present standards of reliability. While compactness of design and saving of weight are of great importance, the even more important element of reliability is not to be unnecessarily sacrificed. For certain classes of electrical equipment there are other features which finally determine their sizes and weights. In such cases it is neither necessary nor desirable to utilize the lowest standard of distances permitted by the above tables. Wherever it is practicable by ingenious design and/or suitable barriering, to maintain adequate clearances and creepages in even the most compact designs of equipment, this is the preferable course to pursue, and the one which will be required.

DESIGN STANDARDS.

We now come down to the main purpose of all these standards—these several components, as it were, of balanced electrical machinery designs. The purpose in developing a material standard or a process standard is not to produce just a packet of nice words done up in some special way. No one, not even the purest of "specialists," could find in a *specification* anything of value in terms of good literature, art, or entertainment. They are intended to be nothing more than just good "*dictionaries*" and suitable "*measuring sticks.*"

We all remember the story of how one idealistic enterprise came to naught because the different builders became confused over words—the Tower of Babel was neither the first nor the last of such ventures to be halted because men thinking in the same terms were unable to understand each other.

So it is that dictionaries (and specifications), by *defining* and *bounding* thought, enable many people of the same mind to get together and have their individual labors add up to a common objective. Furthermore, proper "measuring sticks," are the very necessary indices of progress.

The Indian neeeded no micrometer nor radiographic analysis equipment to fashion his bow and arrow or his battle axe. And it was sufficient for the ancient Cavalryman or charioteer to express the size of his horses in terms of that crude unit of height—so many "*hands high.*" But if much more exact definitions of fit, and of the very exact means of gauging them were not now in force, how could any modern mechanized implement of war or of peace be made to fit together and to operate reliably?

Thus "standards" or "specifications," or whatever one calls specific definitions and specific means of measuring performance are called, are only "*tools*" which enable many men to act in concert without getting too much into each other's way and stopping work to fight about it.

ESTABLISHMENT OF NEW NAVAL BASES.

The foregoing appears so self-evident as to seem to require no explanation—yet the author believes such a clarification at this

time is necessary to the success of the objective set forth in this series of discussions. Everyone with whom he has talked, since the publication of Part I of the series, has exhibited great interest in it and general agreement in principle, but at the same time, have talked in so many *different tongues* as to bring to his mind the biblical enterprise which failed so miserably. So it is that he pleads now—if we are going the same way let us, above all, *speak the same language* lest we become confused and blow up. That is the sole reason for emphasizing something which we all know if we would but think of it.

The foregoing is not meant to deter anyone from making any and all the constructive criticisms and suggestions which he may desire to offer whenever a navy "*standard*" is being developed—and naval standards are always in course of *further* development to meet new needs and new situations—they are never finally fixed. Let us never cease to be watchful about the correctness of our definitions and of our measuring sticks, but let us not argue at cross purposes over *that thing* which we are trying to accomplish. Let us keep on with our "tower" by avoiding the "Babel" of misunderstanding.

Starting then from this point, and assuming that our *standards* are as nearly correct as it is practicable to make them, or that they will be corrected and kept so with the help of others, let us consider them as our *basic building blocks* for structures suitable for naval shipboard uses. What then do we do about them?—Why not use them to establish some new naval bases?—invasion bases if you will—not the kind of bases established on islands or mainlands, but rather those kinds which are best established in the *laboratory,* on the *drawing board,* and in the *work shop.* Might not such new bases be established in the following strategic locations:

(*a*) Individualized Insulations.
(*b*) The several lives of Insulation.
(*c*) Mixed Insulations for better balance.
(*d*) Improved Thermal Paths.
(*e*) Closer ratings.
(*f*) Balanced machinery designs.

INDIVIDUALIZED INSULATIONS.

As pointed out in Part I of this series, the principal weakness in the present use of the *system* of Classes A, B, and C insulation is that the definitions cover too much ground in too few strides. Granting the fact that this was the first real plan for "rating" and that it has served well its purposes for many years, the recent developments in chemistry together with those which most assuredly lie just ahead, mean just one thing if this system is not given some general overhaul and reconditioning treatment—either some materials now do receive a higher rating than they deserve, or else others are held to too low a classification—either we play too loose and take a chance on service reliability or else we act too conservatively—in either case we are in for a technical revolution unless we have the proper technical evolution, and in time. This then amounts to a plea for freer play in evolution, because progress in chemistry will not be stopped no matter how tight we shut our eyes.

Without attempting to repeat any of the arguments on this score, already advanced in Part I of this series, the author does wish to again point out that all materials in Class A are no more equal than are all men with white skins—and that failure to appreciate this point forces us into the dilemma of either taking too much of a chance or of playing too safe. As between taking a chance of 25 per cent too sorry or playing 25 per cent too safe, there is only one answer—where vital machinery and equipment is concerned it is necessary to play safe.

It is believed, however, that there is another and a better answer—why play either too sorry or too safe?—why not split the difference?—why allow such coarse adjustments to blind us?—why not seek finer division points, so as to enable us the better to hit the mark? In short, coming back to the previous analogy on exactness of definition and accuracy of measurement as an index to progress, why not develop *more accurate "rating sights"?*

So, in an effort to save that 25 per cent-35 per cent and still not run any greater risk than heretofore, why not streamline the Class A, Class B, and Class C system so as to retain its protective

features and yet not be handicapped by it? Even after a start is made in this direction it will still take some time to effect it—but the sooner we start on the job the sooner it gets done.

THE SEVERAL LIVES OF INSULATION.

Recognizing the fact that it is improper and unfair to criticize any plan unless and until a better one is brought forward to take its place, the author now offers what he believes is a broader plan. And he hopes that it will be subjected to such a "going-over" as even its most severe critics may be capable of. The plan now offered is somewhat hazy in spots, incomplete in others, and far from final crystallization. That which is good about it cannot be hurt by criticism, while that which is visionary cannot but be helped by an attack on it. It may be that the meeting of such assaults upon it might help the author in crystallizing his own views further. At any rate it is offered to be shot at.

In essence the plan is to consider each insulating material or combination as an individual, instead of as one of many in the same *class*. In the plan it is proposed to completely ignore the *caste system*, and to credit each material with that full measure of respect and confidence which is due it. In this plan no material of inferior properties will be able to ride through on the skirts of its superiors in the same *class*, nor will those of superior properties be held down to the level of the poorest of the group.

Furthermore, since the matter of *superiority* or *inferiority* is one of specific application rather than of something inherent in the material, per se, it becomes a question of *relativity*—the same material can be *superior* for one purpose or one set of conditions and yet *inferior* for another purpose and under another set of conditions. So, according to the proposed plan, each material would not only be judged according to its individual worth (instead of being lifted up or weighted down by its classmates), but *each* would have *several different ratings*, depending upon types of applications and sets of conditions.

For example; and just by way of getting started, why not assume that many solid insulating materials might have as many as seven temperature *limits* or "lives" (two less than that of the

proverbial cat). As pointed out in Part I of this series, a material may even have many more lives, depending upon circumstances, but seven would be enough to start with. Let us assume these seven to be as follows:

(1) The temperature, in degrees Centigrade, above which the particular material begins to exhibit marked *loss* of chemical "*stability.*" The chemical term "triggering" is not the correct one here, because we are not talking about anything quite that fast or so near the brink, but, in the absence of a better one it may serve to convey the idea of a temperature limit above which things begin to happen so rapidly that under no circumstances is the material to be subjected to it for any appreciable length of time—but below which temperature limit, and particularly in the case of emergencies, the material can be considered safe, provided the plastic deformation does not become too great for continued subsequent operation. As this might represent an "emergency" operating condition, some loss in the "permanence" or "longevity" of the machinery is to be expected under it—let us, therefore, and until a better term is available, call it a "*pinch-hit*" temperature rating of an insulating material.

Since some materials are undoubtedly better in this respect than are some others, our very act of evaluating materials on this basis might lead to machinery designs with more "overload" or "*pinch-hitting*" capacity for emergencies. It might be a grand thing to be able to successfully finish off a fight and to limp home or to the hospital under one's own power, even if the act did shorten one's life a bit.

(2) and (3) The temperature, in degrees Centigrade, above which the *thermo-plasticity* or plastic deformation of a material prevents its successful use. Since plastic deformation is a function of time, even at a given temperature, we might assume two conditions in respect to time—one a *long-time* condition (2), and the other a *short-time* or *emergency* condition (3).

(4), (5), (6), and (7). The temperature, in degrees Centigrade, above which *long-life* under more or less normal service conditions, might be sacrificed. As pointed out in Part I of this series, such

longevity depends not on temperature alone; several other factors are involved, such as whether the material is *serene* or *stressed,* and whether it is *protected* or *exposed.* Let us, then, divide longevity or *permanence* according to certain of those factors which affect it, somewhat as follows:

(4) Serene, protected
(5) Serene, exposed
(6) Stressed, protected
(7) Stressed, exposed

Not all materials would exhibit plastic yield because only some of them are thermo-plastic. Some others are thermal-setting. But even the thermo-plastic ones may have fibrous or other reinforcement or possess restraining components to limit the plastic deformation. Also some other insulations have high and definite physical properties at temperatures much beyond those at which they could be satisfactorily employed, because of still other considerations. Furthermore, in the case of still other insulations, the effect of very high or of prolonged moderately high temperatures would be one of degree of oxidation instead of plastic yield or of loss of plasticizer.

So, in the " seven lives " outlined above, it is neither suggested nor intended to fit each material neatly into all seven categories. What is actually intended, is to provide for enough different categories to permit the machinery designer to determine *which* of the *seven* represent the *limitations* of a given *material* in a particular application.

What is being sought, is an arrangement for such a choice of branding irons as will permit the exercise of some intelligent discretion as to what goes into each corral—the author just does not believe that all these insulators belong to the same order regardless of where one comes upon them. Unlike the brand mark which signifies ownership of an animal under all circumstances, the branding or classifying now proposed is *relative* and *functional,* varying with the *primary duties* involved.

Under such a plan, a material *rating* tabulation of insulations might be set up somewhat after the following fashion:

Specific Insulator Material	Chem. Stability Below .... ° C. (1)	Plastic Yield		Permanence			
				Serene		Stressed	
		Short-time (2)	Long-time (3)	Protected (4)	Exposed (5)	Protected (6)	Exposed (7)
A							
B							
C							
D							
Etc.							

No values are shown under the above tabular headings, because the author does not wish to start any controversy which might interfere with the possible acceptance of such a plan *in principle*—the details to be worked out later. With everyone having something different to sell, such a *Babel* might be unloosed as would interfere with further explanation—and with further building.

But, if it be conceded that there is a wide difference as between the ability of various materials *to take it,* then the usual "classes A, B, and C" limits could be disregarded and the machinery designer allowed to pick his particular *material* for the particular *purpose,* resting confident that if he did not exceed its *individual limitation,* in that particular job or *location,* everything would be all right as far as the *electrical insulation* of the machinery was concerned.

Again it must be emphasized that this idea does not depart in principle from the class A, B, and C system—it is merely an extension of that system—less of generalizing and more of acting on a *bill of particulars*—an attempt to gain in horsepower or kilowatt rating by a system of *individual* examinations instead of entire dependence upon the customary *class* or group distinctions.

Certainly this means a lot of work, to obtain the information and data necessary to carry out such a plan—but look what one might get in return for that labor—where else can one gain so much at the cost of so little? Anyhow this will have to be done eventually—why not start now?

MIXED INSULATIONS.

It follows then, if we more or less discard a *class rating* (A, B, C) in favor of an *individualized design* rating, we cease to term a machine a " Class A Insulated " or a " Class B Insulated " machine. What do we care whether a machine has its insulation all of one class or all of another class? What matters it if the same machine has some of each class (A, B, and C), plus some intermediate ones?

This general idea has been toyed with before, under the guise of *notes* on *" mixed insulation,"* occurring in various A. I. E. E., NEMA, Navy, and other standards—but always as a sort of sop to individualists—why not bring this fellow, " Mr. Notes," out from behind his false whiskers, and give him a real reception in his own right? In fact, it is the author's view that we ought to throw in a medal or two for him—all insulation should be *" mixed "* for the best effect.

Now then, if we cease our apologies for using mixed insulation and start pointing to the practice with pride, we begin to get the general idea—the idea of using properly *" proportioned "* insulation—each material suited to its particular *niche* in the design and not for somewhere else. Some spots get *hot* and it takes *heat-resistant* insulation at that spot—but in other spots where the temperature is a few degrees cooler, it would make a much better job if a material having that much less heat resistance, but with a correspondingly greater toughness and moisture-resistance, were employed. *Compensation* being the *law* of *insulation,* when we have anything at all *left over* in one direction it simply means that we have unwittingly *thrown away* what is undoubtedly *needed* in some *other* direction.

The insulation with the somewhat lower heat resistance, but better in some other respects, can even be used next to the higher temperature insulation if the thermal drop through the latter is such that the temperature limit of the former is not exceeded.

Thus we may mix them up as, and to the extent necessary, and then call the machine neither Class A nor Class B. But we must look upon the little chart, giving the particular property limitations on each individual material, to see that for that *purpose,* in that *location,* and under those particular *conditions,* each material can be depended upon for a good, long machinery *life.*

The foregoing should not be interpreted as a plea for more heat resistance or less heat resistance—for greater moisture resistance of less moisture resistance—or for more or less of any one thing. It is intended to emphasize *balance* in *all things*. Above all, it is a suggestion that we be *freed* from too *narrow* a conception of rating—that we cease allowing ourselves to be *blinded* by phrases or clauses which, due to recent progress in the art, do not fit present situations.

It is the author's conviction that if full advantage is taken of the opportunity to establish the above new naval bases—a gain of 25 per cent in rating, with perfect safety, might be realized.

IMPROVED THERMAL PATHS.

As this is a function of the type of insulation in part only, and as it was discussed in Part I of this series in enough detail to convey the main idea, the only purpose in bringing it up again here is to inquire as to what, specifically, might be done about it.

Why not throw away the "conventional allowances" commonly assigned to that gap in our knowledge between what we actually *measure* and what we merely *assume* to be the limiting *hot spot?*

This idea occurred to the author some years ago, and, as a result, a series of tests were made on various manufacturer's coil designs. The object of the tests was to determine if there was any definite and fixed relationship between the *electrical resistivity* of the copper in a coil winding and its *thermal resistivity*. In this connection it is to be remembered that, in general, the paths of electrical flow and of thermal flow are *transverse* to each other; i.e., the electric current follows the coil convolutions; whereas, the heat flow from the inside of a coil to its outside is directly across the wires and their surrounding insulation.

The facts are that an electrical winding is, usually, in part exposed to varying degrees of windage, in part to static air where all is radiation, in part to surrounded iron or to surrounding iron which may or may not be generating more heat than does the copper; and in further part, to surrounded metal or enclosing metal parts which do not generate but only conduct away heat due to varying degrees of contact and/or proximity to the windings. This all serves to complicate theories, assumptions, measure-

ments, etc., so that it is a far from simple matter to make any general predictions not based on empirical data.

But the series of tests did do one thing—it seemed to show that if one were content to arrive at a *lump sum* figure which included everything and made no pretense of separating anything, there was a definite *ratio* between certain results, which seemed to be representable by a *constant* for that one design and set of conditions, was expressable *numerically* in much the same way that one uses *ohms,* also a *ratio,* as a *constant* for a particular conductor composition, treatment, temperature, etc.

The purpose back of trying to find a *constant* was, of course, to permit the "*conventional allowances*" to be *individualized.* One does not make any conventional allowances for the electrical resistance of a conductor; he measures it and relies on "Ohms Law." Why not take specific *thermal drops* into account the same way we do electrical or *voltage drops?*

For example, if one coil design shows such a *slight differential* between its *average* temperature and its *lowest* one (rise by resistance versus rise by thermometer), the *ratio* of this difference to the value of the total heat dissipated is a very *low* one, indicating a *low slope* to the curve of temperatures within the winding. Thus there is *low resistance* in the path of heat, and the *allowance* for that thermal drop could also be a *low* one.

On the other hand, if there is a *high* differential according to the two methods of temperature measurement, producing a *high ratio* in terms of the same total heat dissipated, this indicates a *steep slope* to the curve of temperatures within the winding. Thus there is a relatively *high resistance* to the flow of heat and the *allowance* for that higher resistance should be proportionately greater.

Specifically, then, why not have a *sliding scale* of *allowances* instead of the present fixed scale, the *allowance* used in the individual case to be based upon the *ratio* or *constant* which has been found by test to apply to the particular winding of the particular machine for the particular operating condition?

If, then, one design needs only a 5 degree C. allowance instead of a 15 degree C. allowance, it has saved up to 10 degrees C. which could safely be applied to the permissible temperature rise.

This 10 degrees C. saved, plus the other 40 degrees C. already permitted, gives a total of 50 degrees C. now available for rating purposes. In short, a 25 per cent increase in rating.

On the other hand, in a poorer design where the drop is actually 25 degrees C. or 10 degrees C. more than the present conventional allowance, the machine is already overrated. Actually a bonus has been allowed for the type of design which later fails and serves to discredit all.

Why continue to cover all designs, the very good and the very bad, with the same *blanket,* the same conventional *allowance?* Why not offer the *bonus* to the *best* designs, and the *gate* to the *inferior* ones?

CLOSER MACHINERY RATINGS, IN TERMS OF SERVICE APPLICATION.

This also, is a matter which was touched upon in rather some detail under Part I of this series. The purpose in bringing it up again here is that this, Part V of the series, represents a general summary intended to tie all these various questions together into one knot and to inquire what, specifically, could be done about them?

If the poorer machinery designs, with the (1) less "individualized insulations," (2) with the "several lives of insulation" less fully taken into account, (3) with the least effort to achieve "better balance in mixed insulation," and (4) with the "higher thermal drop"—if all of these can be pepped up or else *given* the *gate*—if the *bonus* is *offered* by suitable *design standards* to the *best* designs instead of to the *worst* ones—well, there is *hope* of attaining greater *confidence* in what lies under the *rating blanket*—and with that greater confidence there is a natural tendency to employ *smaller safety factors* (so called), meaning *smaller ignorance* factors. This all helps.

If, however, there is added to the matter of greater confidence in the reliability of machinery, the further matter of a more careful selection of machinery sizes, characteristics, etc., to fit the particular naval applications involved, a still further saving is possible.

As this latter factor has more to do with machinery application than it does with electrical insulation as such, it will be dealt with only briefly herein. There is, however, one very important tie-in with insulation which might be pointed out, because it does have a great deal to do with the machinery application.

This matter concerns some of the "seven lives of insulation" referred to earlier in this article, particularly those which might be termed the "*overload,*" or *pinch-hitting,* or *emergency* factors, i. e. those which represent "*short-time, all-out*" service factors. Here we need *stout-hearted* things even though we expect that the terrific strains will mean a "*shortened life*" over that which would normally have occurred under more peaceful conditions.

The more common practice of meeting the challenge of such emergency conditions, is to *start* out with a *larger* machine than is normally necessary, on the theory that the *extra* HP or KW *rating* is the solution. So far so good, but, this does not necessarily mean more *nominal horsepower*—the best soldier is not necessarily he who carries the most *beef* on his *hoofs,* but rather he who packs the most *sand* in his *spirit.*

The *big* guy has to be *fed* all the time, just as we have to pay *all the time* for a motor that is *too big*—more *weight,* more *space,* less *efficiency,* lower *power-factor,* and more *dollars.*

But the *little* guy who has the extra *stamina* to take it for a little while is a better buy—he *costs less to operate* normally and only requires the *extra rations* during the emergency. The only question involved is whether we can build him *tough* enough to do the job when the going is rough. Nature does it, not by putting more *beef* on *bones,* but rather, by tucking away some *glands* which operate *automatically* in an *emergency*—some call it *sand* or *grit,* but the doctor refers to it as *adrenalin.*

What this all adds up to is *overload* or *reserve* capacity. And it is the *insulation* which must provide it. This does *not* mean any *more* insulation—it means a *selection* of *insulation* with this one of the *several lives* definitely in mind. If nature always *plans* the extra *glands* for *survival* purposes, why cannot we?

BALANCED MACHINERY DESIGNS.

If any reader gets the idea from the foregoing that the Navy needs or is asking for *super* machinery or machinery with *super* powers in any *one* respect (with consequent neglect in some other respects) the author begs to apologize—such is not the intention. In fact, *common-sense* and *balance* in all things, not super-sense, is the great need.

If one should point to a beautiful hand carved motor running merrily along with everything at *white heat* and inquire if that were not the very *article* we were looking for, the author could only reply that we already have *motors* to do *work,* steam or electric *heaters* to provide *warmth,* and incandescent (or fluorescent) *lamps* to give us *light*—we can use these *different services* to much better advantage if they are *separated,* so that we can put each in the particular place aboardship nearest the spot where it is most needed. We need *simple* service, not *Rube Goldberg* service.

We need heat-resistance, yes—but we also need *torque*—the *starting* kind, to *break* through static *friction* or to move a *viscous* fluid at its *coldest*—also the *running* torque and the *pull-out* torque, to pull the load through the *tough* spots without faltering—we must have torque or *else.*

And we also need good *power factor* and good *efficiency.* If we lose these to save space and weight, we would have made a bad swap. That swap would cost us to the tune of *larger* switches, *larger* circuit breakers, *larger* cables, *larger* transformers, *larger* generators, *larger* turbines, *larger* boilers, and *more* oil. One cannot borrow from Peter to pay Paul, particularly if Peter happens to be an even bigger and tougher guy than Paul. The need is for *over-all* weight, cost and space-*saving;* and *balanced* measures, not the employment of *freaks,* offers the best possibilities in the line of an *over-all* job.

TEST STANDARDS.

The time allotted for the completion of this, the final article in this series, having been more than used up already, it is necessary to start cutting this discussion very short. This means that, even more so than in all the preceding discussion, the matter of *testing* will be treated from the viewpoint of the *principles* involved, rather than an attempt to elucidate on any particular *details.*

How could any one *set* a *standard* of *anything,* unless he were able to *express* that something either in *numerical* terms which permitted accurate *measurement* or in other such *specific* manner as would assure that its *boundaries* were capable of *determination* by the use of a suitable *procedure* or *test method?* The author wouldn't know—and that is an utterly sincere statement—so he asks you—*what* could be more *basic* than a *test?*

Yet, when we come to the matter of testing, we are faced with our biggest problem—how to *test* the *product* of others, many others, and yet be *free* from the *influence* of mere, unsupported or biased *opinions*—not only those held by *others,* even those of *our own?* So, even before one starts worrying about *what* a standard is, he might properly inquire as to *who* is to make the *test* and *how?*

According to the author's own philosophy, any *standard* devoted to machinery *performance* should, therefore, show about a 20 to 1 ratio as between the *description of the test method* employed and the statement as to the *requirement* itself. In short, for every 100 words used in a specification, the division might be roughly as follows:

Ninety-five words to tell exactly *how* to determine if the requirement is *met.*

Five words to say *what* the requirement *is.*

Obviously, therefore, the author has no intention of really starting out to discuss test methods herein—in line with the whole tenor of this discussion, only *ideas* are being emphasized or questioned herein. If the five parts of this series are intended to deal only in *what* some of the Navy's requirements *are,* the series would have had to be much too long to cover *test methods* themselves. Furthermore, that is a matter so *specific* to any given standard that it is best covered therein.

In general, and wherever the naval application or condition parallels the commercial one, the test methods specified by the ASA, AIEE, IEC, ASTM, NEMA, etc., are used without change; or as modified slightly to cover specific naval shipboard conditions or needs not taken into consideration by the existing commercial standards. The Navy seeks to use whatever it can pick up in this direction, because it has too many *special* problems

of its own (which no one else is trying to solve) to wish to duplicate any work already being done by others. The technical committees and sub-committees of these various Industry Groups, Associations, etc., are continuously being consulted by (and seek consultations with) Navy representatives dealing with *standardization*. Such cooperation is highly successful and, the author believes, mutually beneficial.

There is, however, one field of testing which, because it does involve such intimate knowledge of naval service conditions, some of which is not available for general publication, where the work practically has to be done by or under the direction of the Navy. This has to do with such problems as have been outlined briefly near the beginning of this article. Of these, the greatest paraded under such titles as "heat and moisture-resistance," "aging," "accelerated life," "permanence," etc. So this whole series of discussions has been built almost entirely around these as a "theme."

And to further emphasize this point, the reader's attention is invited to the following:

Part I—Viewpoint of the Last Twenty-five Years.

Part II—Viewpoint Based on the Last Fifty Years.

Part III—Viewpoint Based on Looking Backwards 2500 Years.

Part IV—Aging, According to "Milleniums."

Part V—How May the Viewpoint Be Improved?

The reason for looking at a *view* from *more* than *one angle* is to obtain *perspective* or *depth*—you see a little more than just one side alone—a little more than just the side closest to you. A naval *range finder* uses *two angles* to find the *distance* to a *target*. The author has deliberately tried to use *four angles*, a double range finder, if you will—and still he makes no pretense of *locating* the *target*. Can you, with all the foregoing in mind, suggest *another angle?*—or can you suggest wherein any one of the angles used by the author may be *off?* Now this is not a boast—it is an *invitation*, a *sincere* one. Who has *another* and a better *range finder* for the *targets* mentioned herein?

Whatever your reply may be—and it is hoped that there will be some—the more provocative the better—it would seem that there might be at least *two* more good *angles* to try. And back of the

trial of these other two, lies the whole story, reason, purpose, timing, and manner of setting forth the ideas in this series on "Electrical Insulation." If either of these plans work out, there could be another chapter added to these first five. If they don't, well, maybe the author might prefer that "*Anon*" had signed the first five.

SUMMARY.

In spite of the general title of this series of discussions, there has been no intent herein to "peddle insulation" as such. The subject has not been handled by a "specialist," nor is it intended for consumption by "specialists." It is a "layman's" idea, written in a "layman's" language, without thought of being very technical. It is chiefly concerned about how one can *procure service,* of the most reliable sort, guaranteed for *long life,* done up in the *lightest* and most *space-conserving packages*—big, little dynamos.

And reverting back to the *three whys,* imagine yourself in the service of the Navy; then how about answering them yourself:

(1) Should *anything* be done?

(2) Is *this* the thing to do?

(3) Is *now* the time?—if not, *when* would be a good time?

DISCUSSION.

Discussion by Professor H. F. Nordstrom.*

The following discussions by Professor H. F. Nordstrom and J. H. Strandell complete the discussion in the Journal *which was started by the publication in the August, 1940, issue, of Mr. Strandell's article "Controllable Pitch Propellers."*

Through Mr. Strandell I have been given an opportunity to take part in the discussion of his article on "Controllable Pitch Propellers," published in the August, 1940, issue of this Journal. A part of the article is based upon data and charts derived by me from an investigation of controllable pitch propellers, the results of which were published in the Swedish technical journal "Teknisk Tidskrift." This article was later translated by Mr. Strandell and published in the February, 1940, issue of this Journal. I take this opportunity to publicly acknowledge my appreciation and thanks to Mr. Strandell for his courtesy and professional interest in translating my article. I feel justified in entering this discussion because Captain Smith's criticism concerns my own paper as well as the article by Mr. Strandell.

I wish to state, at the outset, that Captain Smith has in certain respects misunderstood the ideas expressed in both papers. A complete discussion of all of Captain Smith's errors would add very little to the understanding of the subject under discussion, controllable pitch propellers, and I shall restrict myself to only a few aspects of his discussion.

> Captain Smith states on page 620 quote, "Please refer to Mr. Strandell's Figure 28 on page 440. He credits this Figure to Nordstrom 6. This figure shows the RPM. and SHP. per propeller required to drive a torpedo boat at various

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speeds using propellers of different pitch ratios. It will be noted that close to the curve for pitch ratio 1.2 is a dashed line showing the pitch ratio for the best propeller at every speed from 40 knots down to 20 knots. It will also be noted that the pitch ratio of the best propeller is so close to the pitch ratio 1.2 at all speeds as to be almost indistinguishable. In short, Mr. Strandell has presented data which confirm the fixed propeller as having almost the best possible efficiency over a wide speed range."

"The other conclusion is that in dropping to half speed, a constant RPM. controllable pitch propeller drops to a region of intollerable inefficiency."

In reply to this statement, and some of the remarks which follow this quotation, I wish to quote from page 108 of my article, referring to Figure 5, which is practically identical with Figure 28 of Mr. Strandell's article.

"From a study of Figure 5 it will be further recognized that the overload capacity of the engine can be used more effectively with a controllable pitch propeller than with a fixed one. In Figure 5 it will be noticed that a curve has been drawn through the minimum points of the curves for constant speed. This curve is located very close to the curve representing H/D=1.11. This is typical for a general case. Furthermore it is typical that the curves for constant speed are very flat in the neighborhood of the respective minimum points. From this it may be established that in general there is hardly any reason to use a controllable pitch propeller in order to obtain a good propeller efficiency at reduced speeds.

"If we required, on the other hand, that the smallest fuel consumption per horsepower hour"—see Note—"should be obtained at reduced speeds, the conditions are quite different, and a controllable pitch propeller seems to offer considerable advantage. In order to study this question closer, we must know the fuel consumption per horsepower hour for the whole speed range of the engine which will be used."

NOTE.—Fuel consumption per hour in the original.

From this we should conclude that the intention of this example concerning reduced speeds has not been, as Captain Smith apparently believes, to advocate a constant RPM. controllable pitch propeller. On the contrary, this example illustrates that with the controllable pitch propeller at certain speeds of the ship we have an opportunity to select an RPM. where the fuel consumption per hour is reduced to the minimum. Another illustration of this may be found in Figure 10 on page 111. The power plant in this Figure is assumed to be two De Laval steam turbines without cruising turbines. It is obvious that with another type of machinery the minimum fuel consumption problem would have been a different one. But, on the other hand, with the fixed propeller we are entirely limited to a certain RPM., and, therefore, the fuel consumption can only be what the propulsion machinery offers at that speed.

Captain Smith's statements on page 621 in regards to Mr. Strandell's Figures 30 and 31 clearly indicate that he has misunderstood the purpose of those charts. The Figures in question are, on the whole, almost identical with my Figures 1 and 4 respectively.

Let us make a brief simplification of this problem and say, for example, that Mr. Strandell's Figure 30 illustrates the variations of pitch ratio, power and propeller thrust of a tow boat connected to towing objects of different resistances such as various numbers of barges. At the same time let us assume that the torque of the engine is constant at full torque value such as would be practically obtained for example with a reciprocating steam engine with constant cut-off. We notice that with a fixed pitch propeller the RPM. and the horsepower decrease relative to the increase in towing load and both obtain their minimum values at stall pull.

I have often heard operating engineers on tow boats or ice breakers equipped with reciprocating steam engines complain that the engines became weaker the moment the tow or push power was needed. They mean, of course, that with the engines already giving full constant torque, they cannot meet increased torque demands. With the controllable pitch propeller we can adjust the propeller pitch to each load so that RPM. and horsepower have the same

maximum value. In other words, in this example it is shown that with a controllable pitch propeller we have the advantage that full horsepower at all loading conditions may be fully utilized. In such a case, therefore, we are not primarily concerned with the question of which propeller has the higher efficiency.

I would like to deal with several other points in Captain Smith's criticism, but I am unable to write a more extensive discussion at present because of limited time due to the poor Transatlantic communications.

In conclusion it should be added that the problem of controllable pitch propellers deserves a greater interest and a more thorough research. I am quite convinced that the controllable pitch propeller can be used to advantage in a greater number of applications than so far has been the case. See Note.

TRANSLATOR'S NOTE.—Dr. Nordstrom refers to the use of the controllable pitch propeller in Europe.

Translation by J. H. Strandell.

Checked and approved by C. Richard Soderberg, Professor of Applied Mechanics, Massachusetts Institute of Technology, Cambridge, Mass.

Discussion by J. H. Strandell, Member.*

It is entirely proper and necessary to give a complete description of the Kaplan turbine in an article devoted to the design of a controllable pitch propeller. The reason is simple enough if one realizes that both the Swiss and the Swedish Kaplan turbine designs and the experiences encountered in their evolution are responsible for the rebirth of the reversible and controllable pitch propeller. We cannot afford to disregard those designs which already have proven themselves to be entirely feasible and strongly point towards the future development of the controllable pitch propeller. Those pioneering designs are the fundamental basis for the further development of the controllable pitch propeller. Therefore, it is quite difficult to understand why the critics do not comprehend the reason for including such a history in an article concerning the design of a controllable pitch propeller; or why the critics should misconstrue the author's phraseology so completely as to say that the history of the Kaplan turbine was included in the article because the author believed that Kaplan turbines and controllable pitch propellers followed identical laws. Naturally, it was never the intention to make such an erroneous statement. But, nevertheless, there are some mechanical similarities between the Kaplan turbine and the controllable pitch propeller which clearly demonstrate their relationship to each other; for example: the forces on the blades, the sealing devices, the exclusion of water from the moving mechanisms, the similar necessity for controlling the large forces necessary for moving the blades, etc.

It is a known fact that a great number of Kaplan turbines have operated from 5 to 10 years without ever being stopped and dismantled for the inspection of the blade bearings and the mechanisms inside the hub. Of course it is true that Kaplan turbines may be inspected anytime they are stopped. In fact, some Kaplan

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turbine manufacturers advise periodical routine inspection of the oil level in the hub in order to determine whether more oil should be added or water be drained from the hub. However, such a problem may be solved in a ship's propeller by using excess oil pressure in the hub and shafting. Excess oil pressure in the hub and shafting, according to the performance reports of the Swedish propeller design, has shown itself to be entirely satisfactory in keeping oil leakage from the hub within reasonable limits, as well as preventing water seepage into the hub. And so it is quite possible to imagine that a controllable pitch propeller based on the Kaplan turbine design may be developed to a satisfactory reliability for use on large ships. Although one must admit that the difference between salt and fresh water, and the higher centrifugal forces will make it necessary for a ship's propeller to be more carefully planned and designed.

It is not the author's intention to convey to the reader's mind by the foregoing statements that a controllable pitch propeller based upon the Kaplan turbine design will be the only successful controllable pitch propeller. In connection with this, it should be remembered that the adopting of European machinery in this country quite often causes the builder a great deal of trouble and expense in readjustment before it will operate successfully.

It is not a common occurrence for a designer to produce a machine that is radically new in all its features. But, on the contrary, most successful devices are the result of a careful study of the sound principles of accepted devices together with analysis of the reasons for the failure of other devices. And then there is a successful unification of the proved features with the redesigned features. In other words, the device in question is simply the result of a study of both successful and unsuccessful devices. Many of the mechanisms studied may be found in the files of the patent office where, if a careful study is made, one will find many ingenious ideas from which to profit, but it is very rarely that one will find just that combination of ideas which will meet his peculiar needs. In the present case the patent office files proved to be of little advantage. Consequently a great deal of time was spent in searching for the simplest possible mechanism containing

the least number of parts in the hub. This task was further complicated by the fact that the size of the hub must be within the permissible limits and yet be strong enough to withstand any excessive external forces which might occur outside of the forces necessary for turning the blades. And furthermore, different sealing devices and bearing arrangements were laid out; hydraulic drives incorporating servo-motors either in the hub or shafting were studied; electrical drive was tried out with an electric motor inside the shaft in the ship; and numerous other designs were drawn up. After these designs were drawn and calculated, they were then constructively criticized by men with exceptional knowledge of mechanical designing engineering. And so after a systematic study of these numerous designs and calculations, there finally emerged the hub design, blade bearings, inside mechanisms, and the method of actuating the blades as shown in the proposed propeller. This device was thought to be a decided advance over all others. In other words, the proposed design has gone through a long evolution of development before the present conclusions were reached. In view of this history it seems unreasonable for any critic to state that the proposed propeller is "drawn almost entirely from advertisements and advertising literature."

Also during this planning for the method of actuating the blades, it was kept in mind that the experience of the past 40 years with the reversible and controllable pitch propellers has invariably proven that the greatest difficulty to be surmounted is that connected with the large forces necessary for moving the blades. These forces seem to have just as much to do with the frictional resistance of the blade bearings as with the propeller thrust while the engines are under power. Of course, those early designs were poorly lubricated owing to deficient oiling systems, and therefore it might be supposed that the improved designs with the improved lubricating systems have less frictional resistance. But, nevertheless, in order to avoid this problem, a device creating the largest forces possible for actuating the blade movement should be incorporated. It is known that the failure of a designer to realize this has resulted in the breakdown of an experimental propeller.

It is well known to every designer that no machine can be designed on paper and then immediately be ready for manufacture and use. Instead it must go through a tedious period of testing and investigation in the experimental laboratory before it is fit for an actual practice trial. And therefore it is believed that the testing procedure for Kaplan turbines as described in the article and illustrated in Figure 3 may convey to the mind a feasible testing procedure for a reversible and controllable pitch propeller. It was the author's intention to illustrate that device for testing Kaplan turbines in order to point out that such a device, modified to suit the conditions, might be adapted for the testing of ship's propellers. For instance, the hub mechanism and the very important sealing devices could be arranged in a rigging as shown in Figure 3 of the article except that this rigging should be encased in a tank of sea water of maximum salt content and the pressure varied in the tank according to the pressure to which a submarine may be subjected at various depths. The hydraulic and centrifugal forces of the blades may be replaced by corresponding spring forces and the hub mechanism should then be worked for a long period of time to determine the correct design as well as to determine the maximum permissable bearing pressure.

Undoubtedly a careful combination of testing and design will result in a reliable design which would be applicable to large ships in spite of the critic's statement that the unreliability of the reversible controllable pitch propeller makes it acceptable only in " the case of small unimportant craft . . . because their sterns may be hoisted out of water for inspection and overhauled at such intervals as desired." Apparently the critic has disregarded entirely what has been accomplished in Europe not only with commercial vessels but also on large Naval vessels. European vessels are using reversible controllable pitch propellers and they seem to operate even more successfully than its supporters had hoped . . . and this again in spite of the critic's belief that this type propeller may only be used when " the vessel or the nature of its services is such that reliability can be ignored."

So far the purpose of this reply has been an attempt to clearly explain the necessary relationship of the Kaplan turbine to the

controllable pitch propeller development, and also to illustrate a positive method by which to achieve results in propeller development without spending too much money, inefficient effort and unnecessary delay. Such waste of money, effort, and time will furnish the opponents of the device still more opportunities to hamper sound development. But now let us assume that the propeller development in Europe, as described in the article, is merely advertising, and that the application and reported advantages are grossly exaggerated. Assuming all that, we may now start our propeller development in an intelligent procedure with the determination and faith that ultimately we will arrive at a design which is very nearly as reliable as a fixed propeller and which can be used on large naval vessels propelled by Diesel engines or steam turbines.

Such a view may be regarded by the critics as entirely too optimistic; but, nevertheless, even they have admitted that there are some advantages to be derived from a reversible and controllable pitch propeller. They agree that this device can be designed to be almost as efficient as a fixed propeller if only the reversible features of the propeller are used. And so with their voluntary admission of the device's value, it may prove worthwhile to call attention to the fact that technology and science have solved many more difficult problems than this one, and with hardly any similar developments to build upon.

Since the critics also unanimously contend that very little is gained by varying the pitch, let us discuss only the reversible pitch features for the time being.

Let us assume that the ship in discussion uses two propellers which may be reversed either separately or collectively by means of small hand levers or push buttons controlled by the officer on the bridge. Such a device for direct control will eliminate the time-lag caused by the human element when orders have been given by one party to be executed by a second party. And since the cooperation of the engine room personnel would no longer be necessary, mistakes would be practically eliminated, or if made, would be corrected in time. In short, the maneuvering of the ship is completely controlled by only one man.

The device for the remote control of the electrical, hydraulic, or mechanical arrangements for moving the blades from the bridge should not cause any difficulties in regards to development and reliability. In other fields of engineering there are numerous applications of just such devices whose reliable features may be supplemented to those already used on ships.

But although a reversible pitch propeller will simplify the control system it will also add another problem. What can be done to prevent the sudden shocks caused by changing the blades from full pitch ahead to full pitch reverse? In large ships such shocks might ruin the thrust bearings or tear loose the hub from the propeller shaft. Since it is also expected that the acceleration and retardation of the ship will be much greater if the controllable pitch features are incorporated, we may, just for the sake of safety, incorporate them into the reversible pitch propeller design if only in order to prevent these sudden shocks. The permissible speed for moving the blades from full pitch ahead to full pitch astern may readily be determined by tests on actual installations.

The two propellers of the ship are assumed to be connected to Diesel engines, four engines to each shaft. The engines, which are connected to each propeller by fluid or electromagnetic couplings and reduction gears, are arranged in such a way that two pairs of engines are opposing each other and work through the same bull gear. It should be understood that the reversible pitch propeller is not only an effective substitute for the complicated reversing mechanisms in each engine, but also will render antiquated the two control stands containing the combined controls of each engine group. Furthermore, the shaft brakes and their intricate mechanism and hook ups to the control stand are no longer necessary. In addition, when maneuvering, the kinetic energy of the whole rotating system adds to the acceleration and retardation of the ship.

We will find, however, that the controllable pitch features of these propellers which we are incorporating for the mere sake of safety, have several other advantages. First, a slight alteration of the pitch will give a smooth and safe operation of the Diesel engines when at certain speeds of the ship the engine revolution happens to run into critical torsional vibrations. And secondly,

in cases where the engines are difficult to regulate at low speeds, a slight change in the pitch of the propeller will enable it to accommodate for a somewhat higher speed of the engines.

It is apparent that the critics also agree to the value of such advantages offered by the controllable pitch propeller, and so we may almost accept these advantages as accepted facts.

Of course there are sources of trouble in reversible pitch propellers and their devices for remote control, but there are far more numerous sources of trouble in the complicated reversing gears and control systems of various types of Diesel engine power plants which would be removed when reversible pitch propellers are used. Furthermore, the cost of the reversing gears on Diesel engine power plants is so great as to seem a ridiculous waste of money when we realize that the application of a reversible pitch propeller will reduce the cost of the power plant more than enough to pay not only for the reversible pitch propellers but also to pay for a thoroughly exhaustive experimentation of these propellers before they are assembled on the ship.

It may be said in conclusion that the advantages gained by a marine Diesel engine power plant using reversible propellers are as follows:

1. The design and arrangement of the engines will be greatly simplified, thereby eliminating many sources of trouble and saving time and expense.

2. The absence of an intricate control system will ensure greater overall reliability.

3. The engines will rotate in one direction at all times, thereby reducing the number of air starts. Consequently there will be less cylinder liner wear. In short, the up-keep costs will be greatly reduced.

4. The addition of the controllable pitch features as a safety device will also create a flexible propulsion machinery as a mere by-product.

5. The general adoption of the reversible pitch propellers will enable Diesel engine propulsion to be more extensively applied to both commercial and Naval ships, and in particular to Naval vessels requiring multiple high speed Diesel engine installations.

In recapitulation, the foregoing discussion covers the following points:

(*a*) The relationship of the Kaplan turbine to the controllable and reversible pitch propeller.

(*b*) The procedure of developing the author's proposed propeller design.

(*c*) A method for testing a controllable and reversible pitch propeller.

(*d*) The advantages of Marine Diesel engines using reversible pitch propellers and also the advantages derived from the controllable pitch features as a mere safety device.

The author will now endeavor to clarify some points in his article, and to correct a few of the misapprehensions of the critics.

The author's description of the advantages of the controllable pitch features of the propeller is based on Dr. Nordstrom's investigations published in the February, 1940, issue of this JOURNAL. The author was unable to find any other publication covering so many angles of the subject. Indeed, propeller experts informed the author that it was a very interesting analysis of the problems.

In order to stimulate more interest in the controllable pitch propeller, the author wrote his article pertaining to the design developments, methods of testing, and practical applications of the device. The criticisms of the article and especially of the charts bring to mind a little difficulty the author faced during the preparation of his article.

During this period, the author realized that he lacked certain charts necessary for a clear explicit demonstration of the problem at hand. But when several Navy propeller experts were asked for help in preparing such charts, they were unable to provide this help, owing perhaps, to the press of other duties. Essentially, a chart similar to Figure 28 was needed to suit the submarine which was described in the article as being propelled by Diesel engines. The author, being unable to obtain the necessary charts, therefore found it necessary to resort to the use of Dr. Nordstrom's chart which was applicable to a torpedo boat driven by steam turbines. Of course it was realized that such a chart could not as clearly demonstrate the problem as could a chart drawn to suit the case desired.

Commander Gold's Figure 1 (see page 602) represents an efficiency curve of a recent naval vessel. This curve shows that the efficiency is practically constant throughout the range of speed of a conventionally constructed vessel. Here, Commander Gold is absolutely right. But, the introduction of this curve is irrelevant to the discussion because the maintenance of optimum propeller pitch and its efficiency is not our primary concern. What we are offering is an optimum efficiency of the whole propelling plant, not of the propeller alone.

On the other hand, Commander Gold's Figure 2 is quite similar to Dr. Nordstrom's Figure 5 or to the author's Figure 28. Both charts indicate that from the standpoint of propeller efficiency alone, there is little reason to use a controllable pitch propeller. But it is assumed that we are interested in the fuel economy of the power plant . . fuel consumption per hour, and the author believes that his article shows how we might find it advantageous to use a controllable pitch propeller on both Naval and commercial ships.

As yet, the influence of the hub upon propeller efficiency has not been definitely determined. However there are some indications that a hub up to about 35 per cent of the propeller's diameter does not appreciably affect the efficiency of the propeller.

To quote Commander Gold from page 605 of his criticism:

> "'With a fixed pitch propeller on a ship, only one operating function can be efficiently and competely satisfied. This is usually selected for rated speed of the ship and full horsepower developed by the engines with the ship's displacement in the loaded condition, in calm water and no wind.' Please refer to Figure 1 and it will be noted that the fixed pitch propeller satisfies quite well all of the ahead conditions."

Commander Gold apparently refers to a ship with a given displacement and under certain wind conditions, for example: calm water and no wind, Figure 1 refers to such a case. But it should be understood that the author's statement refers to different loading conditions, such as variations in the ship's displacement, different wind conditions, fouling, etc. In other words, Commander Gold's and the author's statements refer to different ships with the same

given engine propeller combinations. Whereas Commander Gold refers to a hypothetical ship where the only change in demand upon the engine-propeller combination comes from a change in the speed, the author refers to a ship where the demand changes arise not only from speed changes but also from changes in a host of other sea conditions which are mostly out of the navigator's control when using a fixed pitch propeller.

Again to quote Commander Gold's criticism from pages 605 and 606:

> "The resistance of a ship at low speeds is fortunately low and, while the thrust of a low pitch ratio propeller is greater at the high slips occurring during acceleration, the actual gain in time to attain full speed from stop is not greatly affected. When the author refers to 'losses of power' it is believed that he has reference to the inability of the engine to produce full power at low RPM., a limitation due to lack of available power rather than an actual power loss resulting from low propeller efficiency."

This is precisely the difficulty with the fixed pitch propellers, the inability of the engine to produce full power at low RPM. The actual gain in maneuvering time with a reversible and controllable pitch propeller has already proven itself to be remarkable not only on small vessels but also on fairly large ships. Experiments to determine the use of the controllable pitch features during maneuvering have established the fact that the pitch of the blades should be changed at a rate which is characteristic for each particular ship. This must be done in order to obtain the maximum acceleration and retardation of the ship. The author's Figure 30 or Dr. Nordstrom's Figure 1 give an illustration of the foregoing statement. But in order to have a clear understanding of this, we should remember that the gain in pulling power can also be said to represent the gain in propeller thrust when starting the ship. Full rotative speed and horsepower of the propulsion machinery can, therefore, be completely utilized. However, only actual experimentation will determine the gain in acceleration and retardation of the ship in relation to the speed at which the blades may be turned.

The following quotation is taken from page 609 of Commander Gold's article:

> "Under the section headed 'What advantages has the controllable pitch propeller for submarine and others ships?' the author discusses the available power for charging batteries on a submarine with engine directly connected to the propeller, or connected by a reduction gear. The point is well taken, and under the assumed conditions it is possible to charge the batteries at a greater rate, as is shown in Figure 28. The total amount of power available for charging being 'A' for the fixed pitch propeller and 'B' for the controllable pitch propeller, assuming the maximum RPM. is maintained. Attention is invited to the increase in SHP. required to maintain the speed of 'thirty knots' for the 'submarine' if the controllable pitch propeller is used at the maximum RPM. The words 'excess power' should be changed to 'available power' to prevent the impression that the fixed pitch propeller requires more power to accomplish its mission, which is to propel the ship. The limitation of MEP. of the Diesel engine reduces the power available for charging batteries at the reduced RPM's."

In reference to this see the author's Figure 28 or Dr. Nordstrom's Figure 5. A study of these charts will show that the SHP. required to maintain the speed of a submarine at 30 knots is somewhat increased by using controllable pitch propellers where the propellers are adjusted to suit the rated speed of the engines. The increase of SHP. is due to the less efficient propeller. In this case, however, we are again not primarily concerned with the maximum efficiency of the propellers. Instead, our objective is to divide up the total available horsepower of the engines in order to obtain the greatest amount of power for feeding the batteries as well as the largest possible amount of power to propel the ship. If, on the other hand, the engines are connected to fixed pitch propellers there will be less available power for charging the batteries because of the limitation of MEP. of the Diesel engines at reduced rotative speeds. This is one of the many strong points for using a controllable pitch pro-

peller on submarines. The author apologizes for his inability to present in the discussion, for reasons already given, a clear and descriptive chart that would have adequately illustrated this advantage of the controllable pitch propeller when it is applied to a submarine.

In connection with the comments concerning Figure 28, it should be mentioned that the chart's purpose is not to advocate a constant speed controllable pitch propeller even though there are a family of curves of constant ship speeds intersecting the family of curves of constant pitch ratio. It can easily be seen from the chart, in spite of its unfortunately reduced size (which incidentally was not the fault of the author) that the controllable pitch features of the propeller are not available for the sake of economy if they should be used to maintain constant RPM. of the machinery at varying speeds of the ship below 75 per cent of its rated speed. But, it should be recognized that there are many times in operating a ship when it is advantageous to run at constant RPM. of the machinery at low ship's speeds without resort to economy which is then of secondary importance.

The author agrees with the critics that the poor efficiency of the low pitch-ratio propellers, plus the decrease in efficiency of the distorted helix of the blades prevent an economical operation of the power plant under these conditions of the propeller when the ship is under way. But the conditions will be entirely different when only small changes of the pitch are made from the normal pitch. In this case greater economy of the power plant will be obtained. The gain in propulsion efficiency can be established by a balancing of the loss of efficiency of the propeller against the gain in efficiency of the power plant.

The optimum of total efficiency of the power plant with its propeller can only be obtained by thorough painstaking investigations. The author realizes this has not been made clear in the article and this very important point is entirely neglected by the critics.

For a better understanding of the controllable and reversible pitch propeller and its problems, please refer to Dr. Nordstrom's work. Dr. Nordstrom is considered to be a leading authority in this field by many experts who have not recognized that his work contains many " absurdities " and " fallacies " as the critics state. It is to be

hoped that someone else will produce an investigation in this subject which may be acceptable to the critics.

Captain Smith sums up many of his arguments with the sentence that "Since, in these two Figures, the three sets of curves n/n_o, N/N_o, and H/D contain implications which are absurd, we can ignore conclusions based upon them." His arguments were concisely stated, except that it should be pointed out that they were based upon an erroneous premise owing to a misinterpretation of Dr. Nordstrom's propeller diagrams (Figures 30 and 31) . . in the article. The critic based his arguments on three cases where the curves indicate that the rotative speed of the engines drops only to 0.66, 0.54, and 0.76 of the rated speed of the engines, and the corresponding horsepower drops in proportion even though the ships are at zero speed. The author begs to remind the Captain that the ships are in stall pull with the engines under power and the propellers turning at 100 per cent slip. (See author's article, pp. 446 and 448.)

The author now realizes that he was entirely at fault when he asked the reader to refer back to Dr. Nordstrom's article for information concerning these charts. That information should have been included in the article so that the average reader would have no difficulty in obtaining and understanding the diagrams before him.

As to when a controllable pitch propeller may be used properly in America, this is a rather difficult question to answer. In view of its obvious advantages we may expect it to be adopted and widely used in types of vessels to which it appears naturally suited, such as: 1. mine sweepers, 2. net tenders, 3. submarines, 4. harbor tugs, 5. fleet tugs, and 6. dispatch boats. It is believed that American propeller experts and Marine engineers are becoming increasingly aware of the need for such adoptions.

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S. S. "PRESIDENT JACKSON."

S. S. *PRESIDENT JACKSON.*

This description of the first of seven new ships for round-the-world service is reprinted from the December, 1940, issue of The Log, published by The Log Publications, Inc., 605 Market Street, San Francisco, California.

Last month a majestic ship passed under a majestic bridge with the majestic hills of California for a backdrop, when the American President Lines' new 'round-the-world steamer *President Jackson* passed through the Golden Gate to enter her home port of San Francisco on her maiden voyage from the builders' yard.

The first of seven sister vessels built to improve the American flag globe-girdling service pioneered by the late Robert Dollar in 1924, the new *President Jackson* far outmodes in design, equipment and speed the predecessor vessels of the familiar "502" type built during the World War I shipbuilding program. In fact there is nothing in the new ship which resembles the older vessels.

S. S. "PRESIDENT JACKSON."

PRINCIPAL CHARACTERISTICS.

Owners: American President Lines.
Built by: Newport News Shipbuilding and Dry Dock Co.
Contracted for: February, 1939.
Launched: June 7, 1940.
Delivered: October 25, 1940.
Classification: American Bureau of Shipping, ✠ A-1 E.

Length, overall, feet and inches	491–10
Length, between perpendicular, feet and inches	465–00
Length, on 27′–03″ waterline, feet and inches	469–00
Beam, molded, feet and inches	69–06
Draft, molded, feet and inches	26–06
Draft, keel, feet and inches	26–09
Depth, molded, to shelter deck, feet and inches	42–06
Camber, in 34′–09″, inches	6
Displacement, molded, hull, tons	16,080
Displacement, total, tons	16,175
Gross tons	9,273
Net tons	5,170
Wetted surface, square feet	43,250
Tons per inch immersion	58.7
Block coefficient	.6574
Block coefficient, at 27′-03″ draft	.6610
Midship section coefficient	.9811
Prismatic coefficient	.6700
Waterplane coefficient	.7630
Propulsion, single screw, geared turbines	
Shaft horsepower, normal	8,500
Shaft horsepower, maximum	9,350
Speed, designed, knots	16.5
Speed, maximum, knots	19.0
Passengers	97
Officers and crew	119

From the upper stack casing which houses the diesel-driven emergency generator set and the smokestack proper with its built-in dust catchers down to the lowermost unit in the machinery spaces, everything is different to the old order of things.

Propulsion efficiency is provided to the greatest known degree by the most modern of machinery and boilers. This, together with streamlined hull form, gives the best possible speed with the power developed. Safety and comfort of passengers and crew have been given the fullest consideration.

Built by the Newport News Shipbuilding and Dry Dock Company to the Maritime Commission's C-3-P design, the *President Jackson* is a single screw shelter deck vessel with raked stem and cruiser stern. The shell of the hull is riveted on the horizontal seams and the vertical seams all butt welded. The interior structure of the hull is principally welded, very little riveting being used.

Extending the full length of the vessel are two complete steel decks, the shelter deck and the second deck, the latter being the freeboard deck. From the machinery space forward is a third deck, and, in way of No. 3 lower hold (refrigerated cargo space), engine room, after deep tank, and steering engine room is a fourth platform deck. The hull is subdivided by seven transverse watertight bulkheads, the collision bulkhead being carried watertight up to the shelter deck and the others watertight to the second deck. There are five cargo holds, three forward and two aft of the machinery space. Refrigerated cargo capacity of 55,660 cubic feet is provided in No. 3 lower hold.

The vessel is of fireproof construction throughout, and all safety requirements are fully complied with in accordance with the Rules and Regulations of the Bureau of Marine Inspection and Navigation, the U. S. Public Health Service, the Convention for the Safety of Life at Sea, and Senate Report No. 184. Structural characteristics have given the vessel the highest classification with the American Bureau of Shipping.

Richaudio Fire Detecting and Zonit Fire Alarm Systems are provided. Lifeboat capacity for 225 persons is provided in two 26-foot, 50-person boats; one 30-foot, 70-person hand gear propelled boat; and one 30-foot, 55-person motor lifeboat.

Accommodations for deck officers are provided on the boat deck immediately under the pilot house and chart room, and the engineer officers are quartered on the starboard side of the shelter deck immediately aft of the passenger quarters.

All passenger rooms are located on the shelter deck, and dining saloon, galley and pantry on the second deck. The passengers' lounge is on the promenade deck extending two decks up to the boat deck with library, card and game room, and cocktail bar in the wings. Indirect lighting is provided in the public spaces. The promenade deck is glass enclosed, and at the open after end is an 18-foot by 30-foot open-air swimming pool.

MACHINERY AND BOILERS.

The single screw propulsion machinery consists of Newport News Shipbuilding and Dry Dock Company's cross-compound turbines with a normal rating of 8500 shaft horsepower, driving the propeller at 85 RPM. through Westinghouse double-reduction gears which gives the vessel a designed service speed of 16.5 knots. At ten per cent overload a speed of nearly 20 knots is readily obtainable.

The high pressure turbine is of the impulse type and has nine stages. With steam pressure of 440 pounds and 740 degrees F. temperature at the throttle chest it develops 4250 normal shaft horsepower at 4504 RPM. The low-pressure turbine has 25 stages and develops 4250 normal shaft horsepower

when turning 2300 RPM. with an inlet pressure of 40 pounds absolute and temperature 300 degrees F., and exhausting to 28.5 inches vacuum. The astern element, of the impulse type, incorporated in the low pressure casing develops 5100 normal shaft horsepower at 1725 RPM. with steam at 350 pounds pressure absolute, and 730 degrees F. temperature.

All rotor blades are of corrosion resisting iron and the casing blades of 70-30 composition. Diaphragms are of cast steel.

The main throttle controls 16 nozzles, and the three-nozzle hand control valves control one, four and six nozzles respectively.

Steam is generated in two Babcock & Wilcox single-pass, sectional-header boilers having horizontal tubular air heaters, interdeck superheaters and drum desuperheaters. The two boilers are designed to generate 75,000 pounds of steam at normal operation, at a pressure of 450 pounds per square inch and total temperature of 750 degrees F. at the superheater outlet. Each boiler is fired by five Babcock & Wilcox Decagon mechanical oil burners arranged for forced draft operation. The boilers are double cased through which the air for combustion is forced. The furnace side-walls are water cooled and of stud-tube construction. Front and rear walls and the furnace floors are lined with B. & W. refractory materials.

Operation of the boilers is automatically controlled with a Bailey Meter Company's Combustion Control and Feedwater Control Systems.

Feedwater is supplied to the boilers through first, second and third stage feedwater heaters by two turbine driven Warren 2-inch four-stage centrifugal pumps designed to deliver 200 gallons per minute against a 600-pound head. The impellers are of the single outlet type with two impellers facing one direction and two in the opposite direction to provide hydraulic balance.

Electricity is generated by three 300-Kw. 240/120 volt, 1250 amperes, 1200 RPM. Westinghouse three-wire, compound wound d.c. generators. These generators are driven by De Laval turbines of 432 horsepower through De Laval 5650/1200 RPM. helical single reduction gears. The generator turbines operate with 440 pounds steam pressure at 283 degrees temperature at the throttle, and exhaust to 28·5-inches vacuum. The main switchboard is of the dead front type built by Newport News Shipbuilding and Dry Dock Company, and equipped with General Electric instruments and Westinghouse switches. Each generator set has its own auxiliary condenser.

Equipment for cooling of the refrigerated cargo spaces with a total of 55,600 cubic feet consists of fifteen vertical air-cooled multi-cylinder single-acting truncated-piston Freon-12 compressors, furnished by the Carrier Corporation. Each refrigerated compartment has its own compressor and evaporator, and normally fourteen are in operation while one is a stand-by which can be operated for any compartment in the case of emergency. Compartments are arranged for 0 degrees F. to 25 degrees F. minimum temperatures. Remote control thermometers are provided for recording temperatures. A separate refrigerating unit, also furnished by Carrier, provides for cooling 10,250 cubic feet of ship's stores space; it is also of sufficient capacity to freeze 400 pounds of ice per day.

Hydro-electric steering gear furnished by the Lidgerwood Manufacturing Company is connected to a contra-guide rudder supplied by the Goldschmidt Corporation. Lidgerwood Company also furnished the anchor windlass and capstans, National Malleable and Steel Castings Company furnished the anchors and 300 fathoms of 2¼-inch "Naco" anchor chain.

Navigation equipment consists of a Mk. 14 master compass, and 2-unit gyro-pilot furnished by the Sperry Gyroscope Company.

For the handling of cargo there are fourteen electric winches furnished by the American Hoist & Derrick Company, each powered by a Westinghouse motor. Weather deck hatches are covered by Tutin steel hatch covers.

The propeller is of solid bronze with four blades, with a diameter of 21.8 feet and 21.669-foot pitch at .7 radius. Its finished weight is 42,000 pounds.

PRINCIPAL AUXILIARY EQUIPMENT.

The auxiliary equipment, other than that previously mentioned, is as follows:

Main Feed Pumps: (2) Warren Steam Pump Co. centrifugal, direct driven by Terry turbines at 4000 RPM. with steam at 440 pounds and 10 pounds back pressure, 200 GPM.

Port Feed Pump: Warren v.s. 10 inches × 6 inches × 18 inches, 70 GPM.

Main Circulating Pump: De Laval centrifugal fitted with double suction mixed flow impeller designed to deliver 13,000 GPM. against 22.4 foot head at 870 RPM. Driven by Westinghouse 100 HP. motor.

Main Condensate Pumps: (2) Worthington 2½-inch vertical centrifugal. Westinghouse motor driven, 140 GPM.

Auxiliary Condensate Pumps: (2) Worthington 1½-inch horizontal centrifugal. Westinghouse motor driven, 30 GPM.

Sanitary Pump: Worthington 1½-inch horizontal centrifugal. Westinghouse motor driven, 50 GPM.

Ballast Pump: Worthington 5-inch vertical centrifugal. Westinghouse motor driven, 600 GPM.

Bilge Pump: Worthington 5-inch vertical centrifugal. Westinghouse motor driven, 600 GPM.

Refrigeration Condenser Circulating Pumps: (2) Worthington vertical centrifugal. Westinghouse motor driven, 250 GPM.

Hot Water Circulating Pump: Worthington horizontal centrifugal. Westinghouse motor driven, 20 GPM.

Ice Water Circulating Pump: Worthington horizontal centrifugal. Westinghouse motor driven.

Fresh Water Pumps: (2) Worthington 1½-inch horizontal centrifugal. Westinghouse motor driven, 60 GPM.

Submersible Bilge Pump: Worthington vertical centrifugal. Westinghouse motor driven, 600 GPM

Contaminated Evaporator Feed Pumps: (2) Worthington vertical duplex 5¼ inches × 5 inches × 5 inches, 35 GPM.

Salt Water Evaporator Feed Pump: Worthington horizontal duplex 3 inches × 2¾ inches × 3 inches, 20 GPM.

Evaporator Make-up Feed Pump: Worthington horizontal duplex 3 inches × 2¾ inches × 3 inches, 20 GPM.

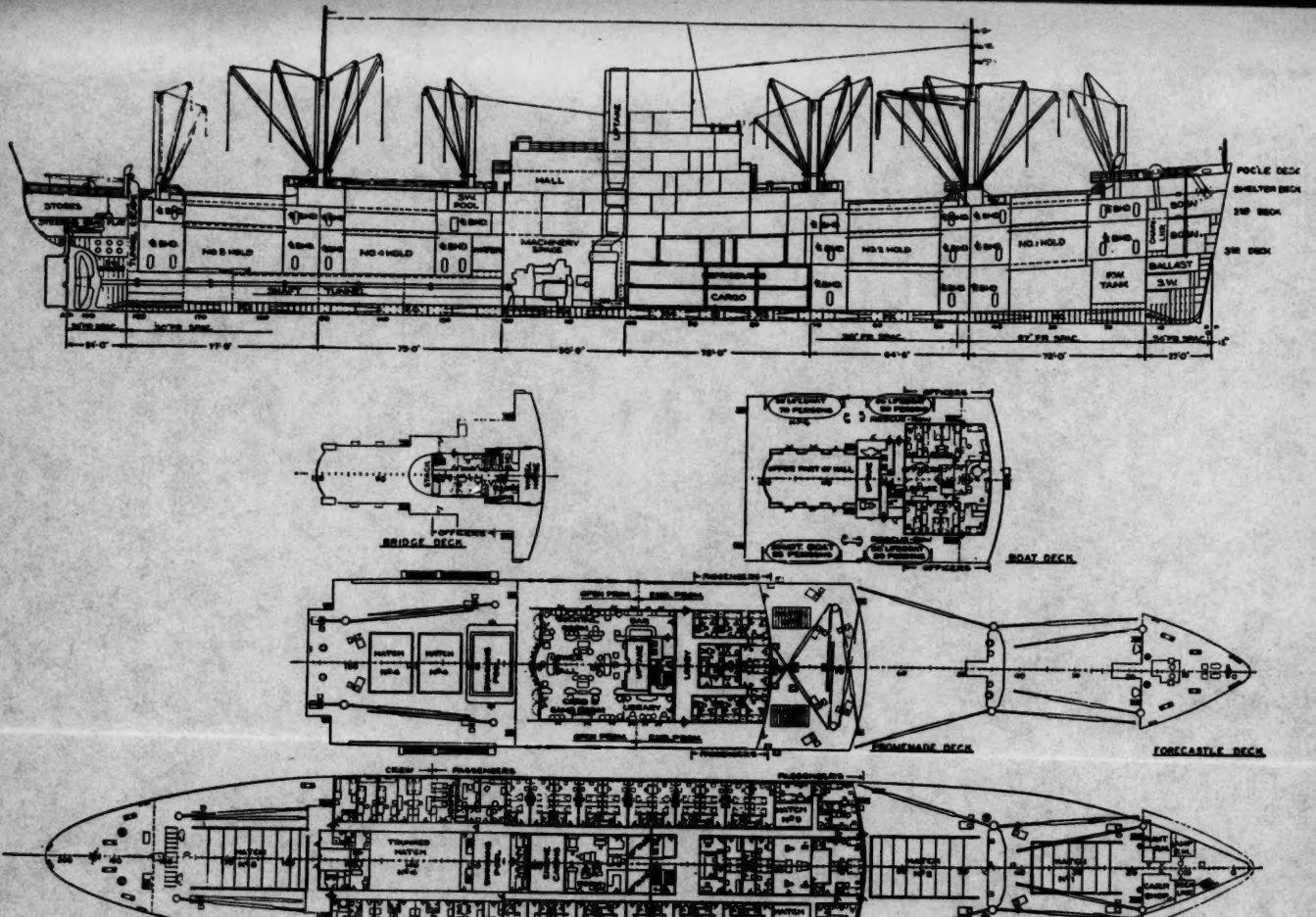
Auxiliary Fuel Oil Service Pump: Worthington vertical simplex 6½ inches × 3½ inches × 12 inches, 15 GPM.

Bilge and Ballast Pump: Warren vertical simplex 10 inches × 14 inches × 18 inches.

Fuel Oil Service Pump: Quimby Pump Co. vertical centrifugal Westinghouse motor driven, 15 GPM.

Fuel Oil Transfer Pump: Vertical rotary, motor driven, 225 GPM.

Cargo Oil Pumps: (3) Kinney Mfg. Co. vertical rotary, motor driven, each 100 GPM.


HALL
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CARGO
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POOLE DECK
SHELTER DECK
2ND DECK
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BOAT DECK
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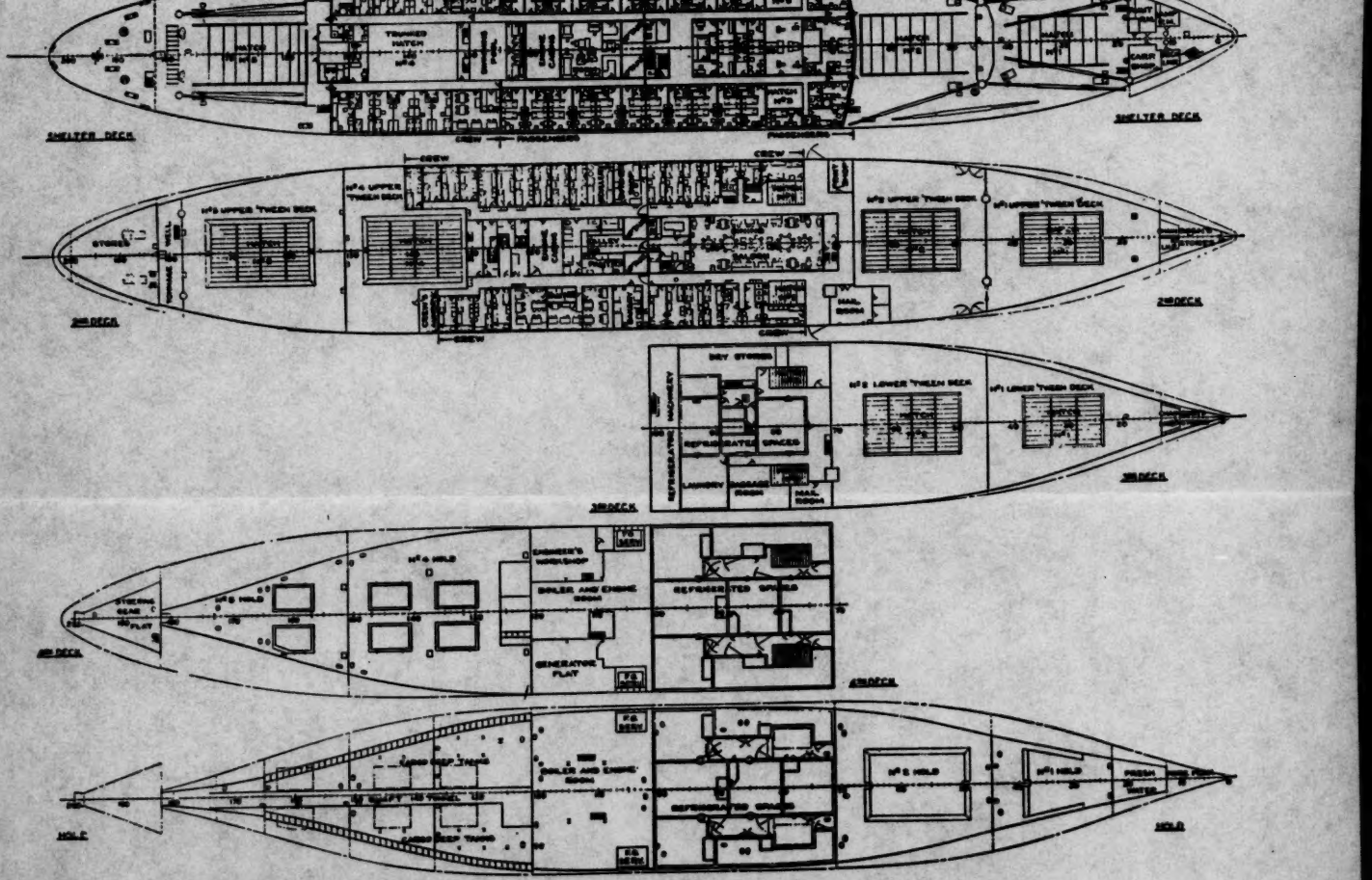
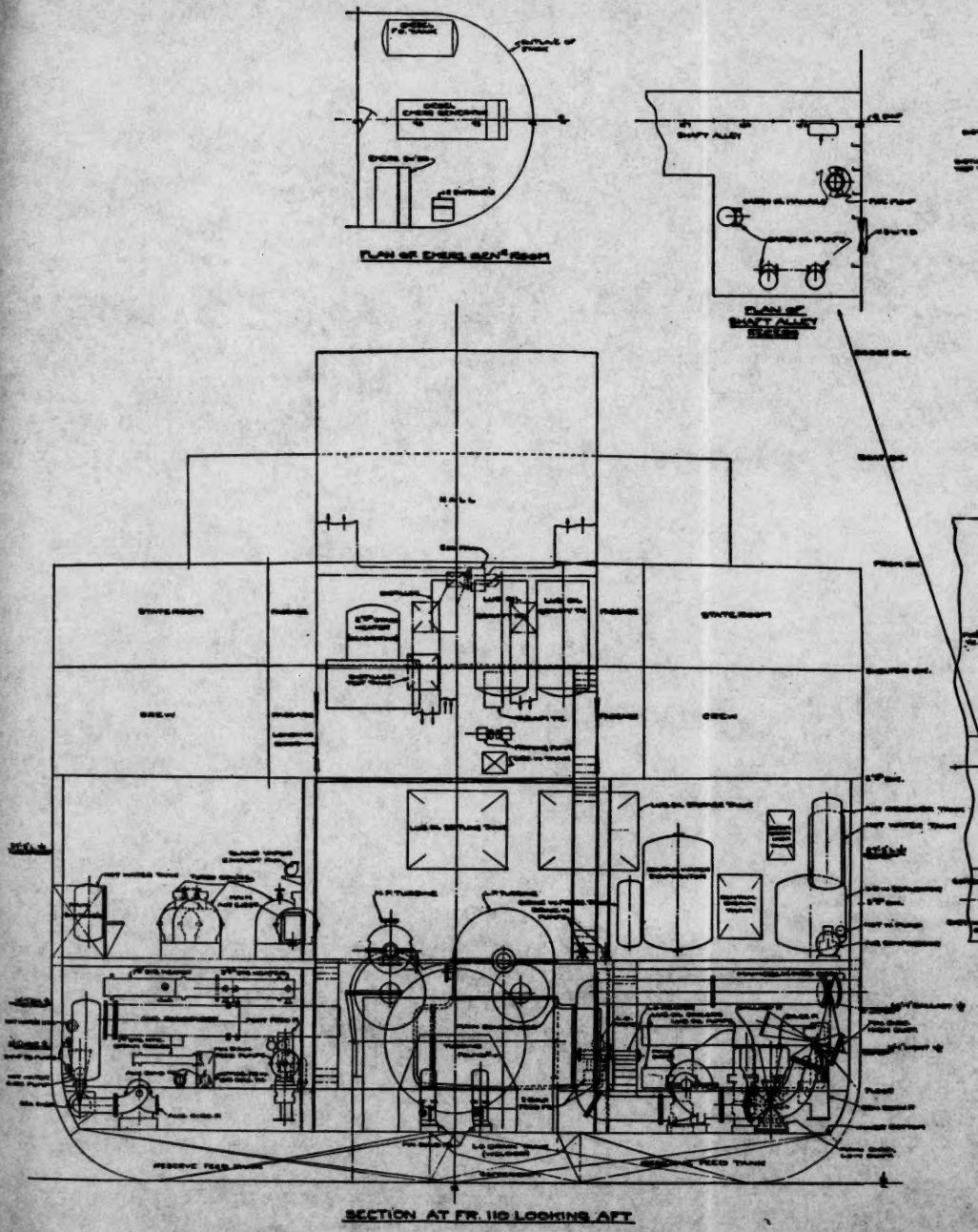
FORECASTLE DECK
OFFICERS
CREW
PASSENGERS
TRIMMED HATCH

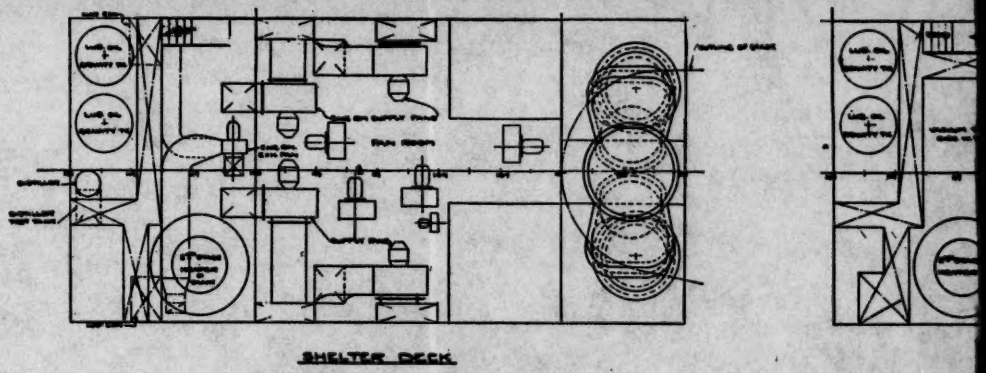


INBOARD PROFILE AND DECK PLANS OF THE *PRESIDENT JACKSON*

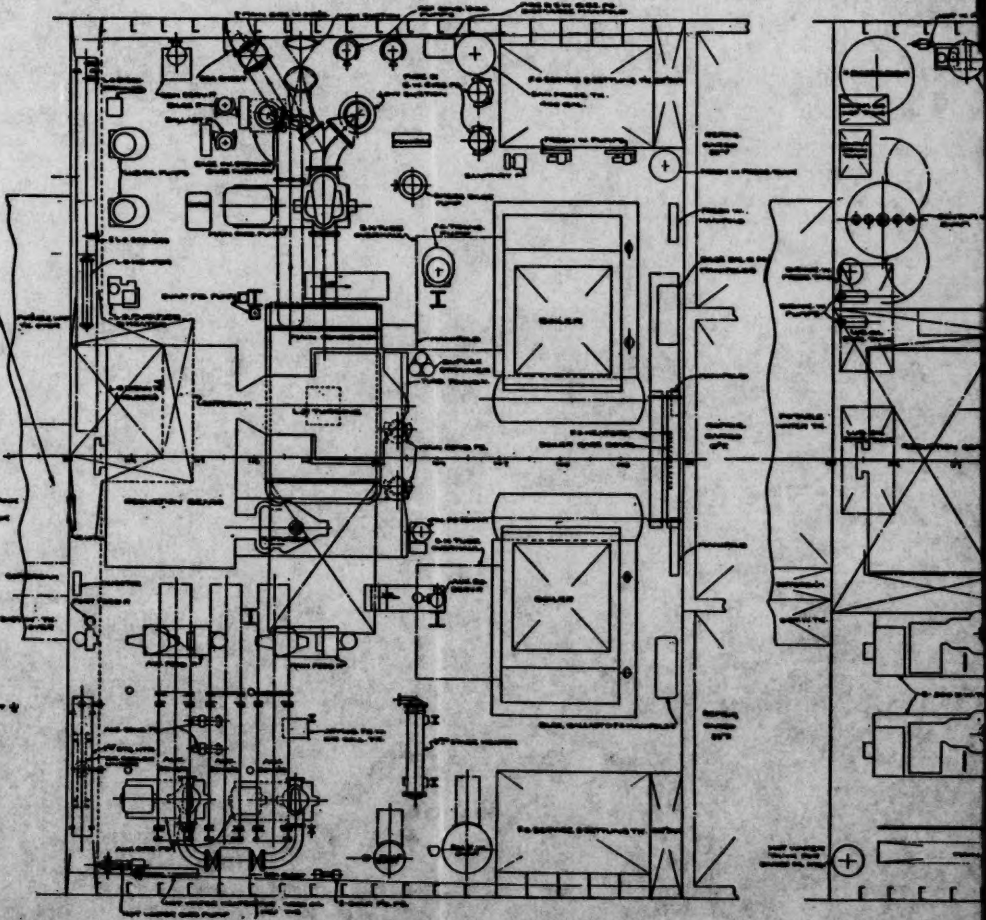


SECTION AT FR. 110 LOOKING AFT.

TRANSVERSE SECTION AND PLANS SHOW

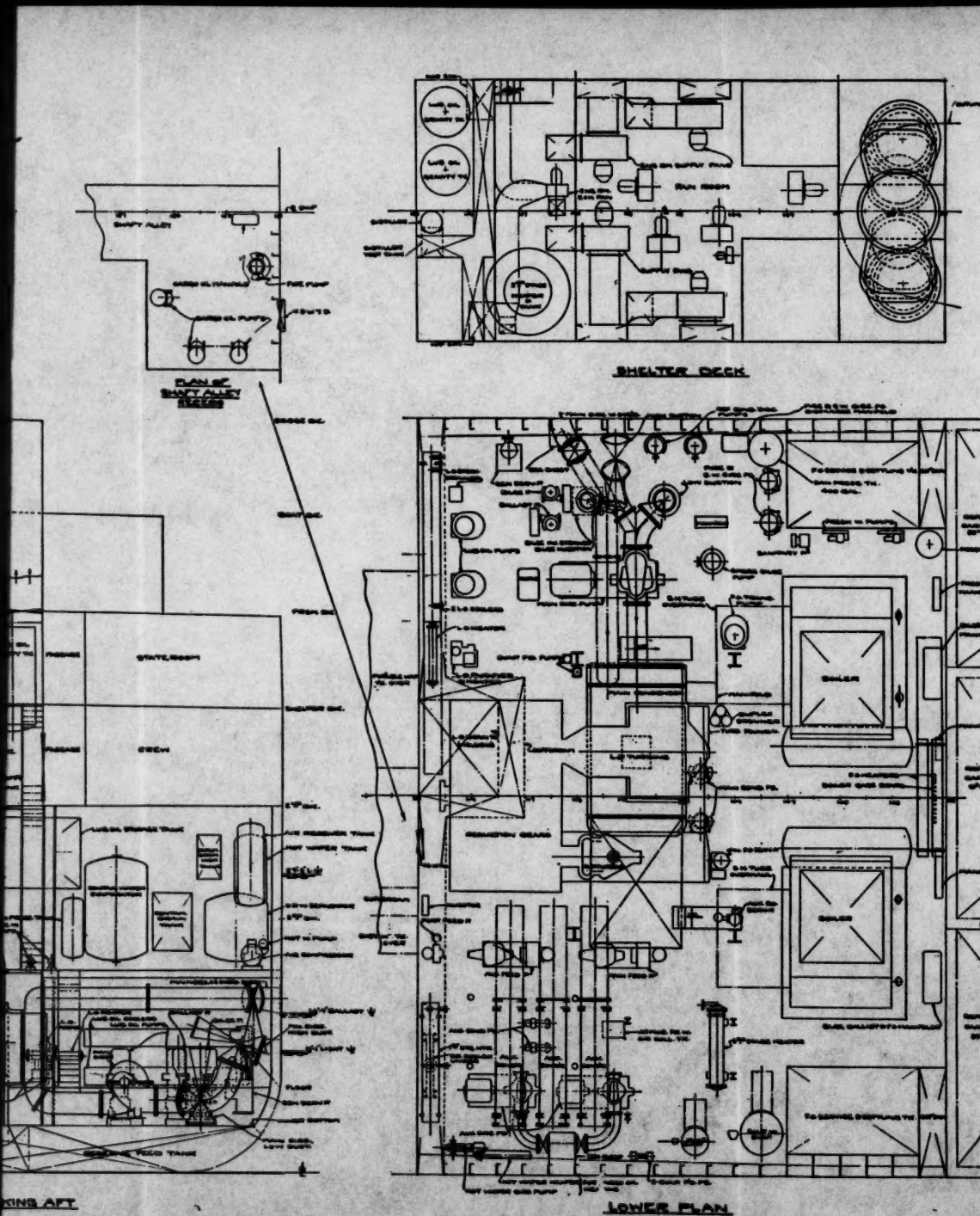


SHELTER DECK

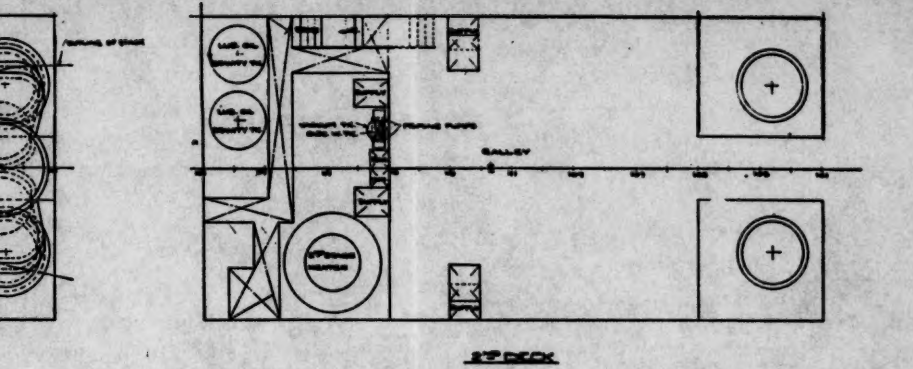


LOWER PLAN

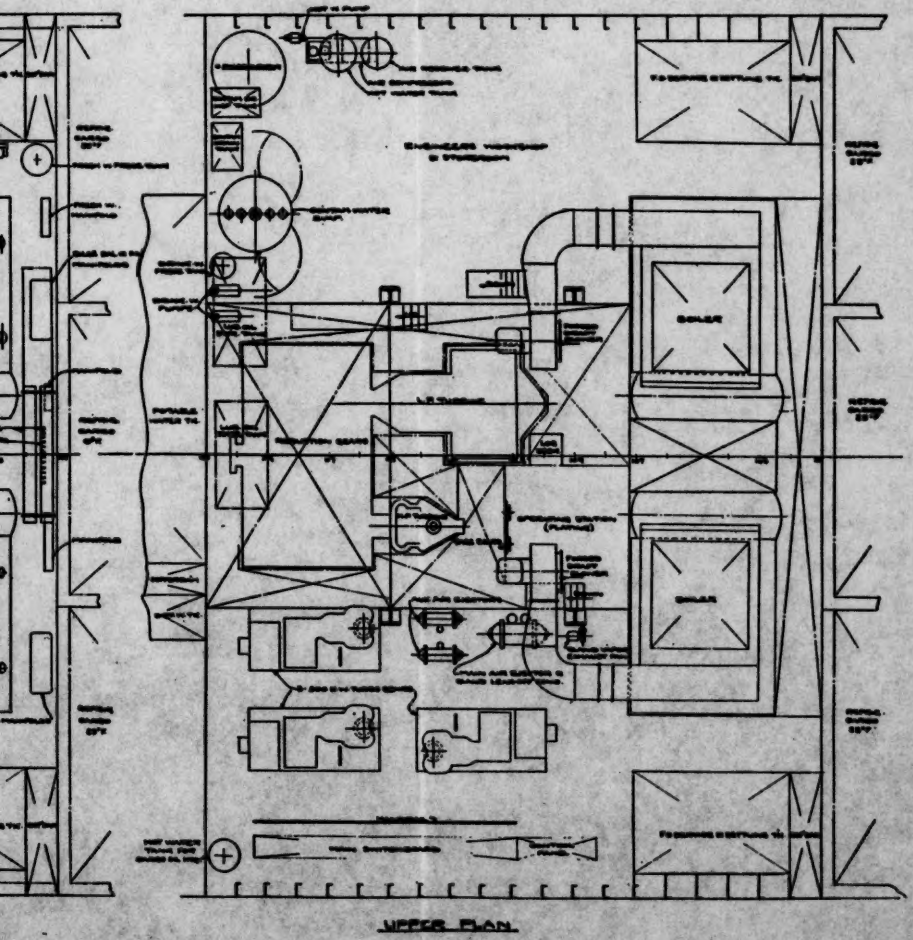
NS SHOWING ARRANGEMENT OF MACHINERY SPACE IN THE *S.S. PRESIDENT JACKSON*



ANSVERSE SECTION AND PLANS SHOWING ARRANGEMENT OF MACHINERY SPACE IN THE S.S.



2ND DECK



UPPER PLAN

HE S.S. PRESIDENT JACKSON

Lubricating Oil Pumps: (2) Quimby Pump Co. vertical rotary, motor driven, 325 GPM.

Feedwater Heaters: (2) Davis Engineering Co.

Deaerating Heater: Cochrane Corporation.

Lubricating Oil Heaters: (2) Sharples Corporation.

Lubricating Oil Purifiers: Sharples Corporation.

Lubricating Oil Coolers: Griscom-Russell Company.

Drain Cooler: Davis Engineering Company.

Air Ejectors: (3) C. H. Wheeler Mfg. Co.

Auxiliary Condensers: (3) Newport News Shipbuilding & Dry Dock Co.

Auxiliary Condenser Circulating Pumps: (2) Buffalo Pumps Inc. Westinghouse motors.

Tubejet Air Pump: C. H. Wheeler Mfg. Co.

Bilge & Ballast Water Separator: Condenser Service & Engineering Co.

Engine Telegraphs: Bendix Aviation Corp. Marine Division.

Telephone System: Control Instrument Co., Inc.

Steering Engine Alarm: Reeve Electrical Co.

Fire Door Control Switch: Trumbull Electrical Mfg. Company.

Evaporators: (2) Griscom-Russell, Reilly submerged type.

Double Bottom Tank Gauges: Long Island Machine & Pattern Works.

Air Compressor: Worthington Pump & Machinery Corp., Westinghouse motor driven.

Emergency Generator: National Supply Co., Superior Diesel Engine Division.

Emergency Switchboard: Newport News Shipbuilding & Dry Dock Co. with General Electric instruments.

Vortex Dust Catcher Washing Pumps: (2) Buffalo Pumps Inc., Westinghouse motors.

Fire Detecting and Alarm Systems: Walter Kidde & Co., Inc.

Lathe: American Tool Works, 18 inches $\times$ 54 inches.

Shaper: Western Machine Tool Works.

Galley Cooking Equipment: Edison Electric Appliance Company.

Room and Public Space Fans: Emerson Electric Co.

Searchlights: (2) Westinghouse Electric & Mfg. Co.

VOYAGE ITINERARY.

Under the command of Captain Carl Hawkins, with Chief Engineer Michael Doyle in command of the engineering department, the *President Jackson* sailed on her first globe-circling cruise from San Francisco on November 23. Thence her itinerary calls for stops at Honolulu, Kobe, Shanghai, Hong Kong, Manila, Singapore, Penang, Colombo, Bombay, thence via Cape of Good Hope with a call at Cape Town; thence to Port au Spain, Trinidad, up to New York and Boston and return to New York. Final departure from New York heads the vessel to Havana, thence through the Panama Canal up to Los Angeles and finally back to her home port of San Francisco.

A splendid ship and circumnavigation of the globe with its ever changing points of interest.

THE POWERING OF SHIPS.

The following outline of the method of making the preliminary calculations involved in the determination of power requirements of a new design, while in general following usual practice, is considered of interest because of its conciseness and orderliness. The paper is by Sydney Albert Smith, M.Sc. (Eng.), M.I. Mech. E., M.I.N.A. (Member) and is reprinted from the May, 1940, issue of the Transactions of the Institute of Marine Engineers published at 73 Amersham Road, High Wycombe, Buckinghamshire, England.

I. Introduction.

One of the principal features of the author's work as the Superintendent Engineer of new construction of a large shipping company is concerned with the powering of new vessels and the design and construction of the main propelling and auxiliary machinery.

The Institute of Marine Engineers is publishing a series of articles by the author describing the method adopted for determining the shaft horsepower required to meet certain specified conditions and also the design of a high-pressure single-reduction geared turbine installation and its auxiliaries.

When a new vessel is proposed it is necessary for specification purposes to define the powers, speeds, steam and fuel consumptions on a given displacement, which the various builders who are asked to tender will be required to guarantee.

The first part of the present article will be devoted to the formulae required for determining the resistance, effective horsepower and shaft horsepower, and the latter part to the application of the method to a proposed vessel.

The writer is a strong advocate of tank tests and the specification should always require the approved builders to have E.H.P. and self-propulsion tank tests carried out.

II. The Powering of Ships.

(1) On the Resistance and Propulsion of Ships.

The two principal elements in the resistance of a ship are the *frictional resistance* and the *residuary or wave and eddy making resistance.*

The frictional resistance may be determined from the law put forward by the late William Froude, *viz.,*

$$R_f = f.S.V^n \quad \ldots\ldots (1)$$

where, R_f = frictional resistance in pounds.

f = coefficient of friction in salt water, which is dependent upon length.

S = wetted surface of hull in square feet.

V = speed of vessel in knots.

n = an index determined from Froude's experiments as 1·83.

TABLE 1.

From Froude's experiments on planks corrected for salt water "f" may be taken as follows:—

Length in feet	"f"	*Length in feet*	"f"
100	.009207	450	.008802
120	.009135	500	.008776
140	.009085	550	.008750
160	.009046	600	.008726
180	.009016	700	.008680
200	.008992	800	.008639
250	.008923	900	.008608
300	.008902	1000	.008574
350	.008867	1100	.008548
400	.008832	1200	.008524

The wetted surface "S" can only be accurately calculated when the lines of the vessel are available but a near approximation of the surface may be made from the formulae given below.

Denny's formula $S = 1{\cdot}7\,L.d. + \frac{V}{d}$ ..... (2)

D. W. Taylor's formula $S = 15{\cdot}4\,\sqrt{D.L.}$ ..... (3)

R. E. Froude's formula $S = V^{\frac{2}{3}}\left(3.4 + \frac{L}{2.V^{\frac{1}{3}}}\right)$ ..... (4)

where, D = displacement in tons; V = volume of displacement in cubic feet;
L = length of ship on load water line in feet.
d = moulded draft in feet.

The constants given in the formulae above are as given by their respective authors but the writer has found in modern practice that the surfaces obtained are too low.

From a number of recent vessels, the mean constants are as follows:—

Denny's formula $S = 1{\cdot}86\,L.d. + \frac{V}{d}$

Taylor's " $S = 16{\cdot}25\,\sqrt{D.L.}$

Froude's " $S = V^{\frac{2}{3}}\left(3{\cdot}7 + \frac{L}{2.V^{\frac{1}{3}}}\right)$

(2) Residuary Resistance.

Residuary resistance does not lend itself to formulae calculation and recourse has to be made to model experiments. In this connection Admiral D. W. Taylor, of the United States Navy, has carried out a classic series of *experiments on 80 models having the following characteristics.

*"Speed and Power of Ships", by D. W. Taylor.

$$\frac{\text{Moulded beam}}{\text{Moulded draft}} = 2{\cdot}25 \text{ and } 3{\cdot}75$$

$$\frac{\text{Displacement in tons}}{\left(\frac{\text{Length on waterline in feet}}{100}\right)^3} = 26{\cdot}6,\ 53{\cdot}2,\ 79{\cdot}81,\ 133{\cdot}02 \text{ and } 199{\cdot}52$$

$$\text{Prismatic Coefficient} = \frac{\text{Volume of displacement in cubic feet}}{\left(\text{Area of midship section in sq. ft.}\right)\left(\text{Length in feet between perpendiculars}\right)}$$

$$= {\cdot}48,\ {\cdot}52,\ {\cdot}56,\ {\cdot}60,\ {\cdot}64,\ {\cdot}68,\ {\cdot}74 \text{ and } {\cdot}80.$$

For each beam-draft ratio and prismatic coefficient a series of residuary resistance curves per ton of displacement were plotted for speed-length ratios from 0·6 to 2·0. The speed-length ratio being,

$$\frac{\text{Speed in knots}}{\sqrt{\text{Length on waterline in feet}}} = \frac{V}{\sqrt{L}} \quad \ldots\ldots(5)$$

The residuary resistance in Taylor's series is plotted per ton of displacement and to obtain the total resistance per ton of displacement R_r equation (1) above has to be divided by the displacement. Hence,

$$R_t = R_f + R_r \quad \ldots\ldots(6)$$

where, $R_f = \frac{R_F}{D}$

Having found the total resistance per ton of displacement we are in a position to calculate the effective horsepower or tow rope horsepower of the bare hull without appendages, as follows:—

$$\text{E.H.P.} = \frac{R_t \times D \times V \times 6{,}080}{60 \times 33{,}000} = {\cdot}0030707\ R_t\ D.V. \quad \ldots\ldots(7)$$

where, D = displacement in tons; V = speed of ship in knots.

1 knot = 6,080 ft.

The E.H.P. is calculated for the full range of speeds on the estimated trial, service and load displacements.

Since the block coefficient and prismatic coefficient are required to enable the residuary resistance to be assessed, it is necessary to approximate these for the reduced displacements.

(3) On the Block Coefficient at reduced Displacements.

From the author's investigations the block coefficient at reduced displacements does not appear to have been given by any of the authorities consulted and the writer therefore puts forward the following.

Over 40 ships of various types were taken for this investigation and the actual block coefficients at various displacements were calculated and plotted on a base of displacement. In every case the curve obtained was an inclined straight line obeying the law

$$\beta = A + b.D. \quad \ldots\ldots(8)$$

where, β = block coefficient, A = a constant and D = displacement in tons.

A and b were found to vary for block coefficients, between 0·56 and 0·73, with the length and breadth of the vessel. For block coefficients of cargo ships of ·76 to ·77, A was found to be constant at ·693 whilst b varied between 3·34 and 5·9.

The following are the results obtained.

Class (1): Length 400 ft.; Breadth 58 ft.; Load block coefft. = ·56

$$\beta = \cdot 4259 + \frac{22 \cdot 2\ D}{1{,}000{,}000}$$

Class (2): L = 520 ft.; B = 74 ft.; Load block coefft. = ·5725

$$\beta = \cdot 440 + \frac{8 \cdot 25\ D}{1{,}000{,}000}$$

Class (3): L = 530 ft.; B = 73 ft.; Load block coefft. = ·646

$$\beta = \cdot 507 + \frac{6 \cdot 6\ D}{1{,}000{,}000}$$

Class (4) L = 630 ft.; B = 82 ft.; Load block coefft. = ·646

$$\beta = \cdot 484 + \frac{5 \cdot 7\ D}{1{,}000{,}000}$$

Class (5): L = 585 ft.; B = 76 ft.; Load block coefft. = ·654

$$\beta = \cdot 5216 + \frac{5 \cdot 7\ D}{1{,}000{,}000}$$

Class (6): L = 518·5 ft.; B = 71 ft.; Load blk. coefft. = ·6575

$$\beta = \cdot 527 + \frac{6 \cdot 5\ D}{1{,}000{,}000}$$

Class (7): L = 530 ft.; B = 60 ft.; Load block coefft. = ·685

$$\beta = \cdot 574 + \frac{6 \cdot 225\ D}{1{,}000{,}000}$$

Class (8): L = 580 ft.; B = 67 ft.; Load block coefft. = ·6875

$$\beta = \cdot 547 + \frac{6 \cdot 35\ D}{1{,}000{,}000}$$

Class (9): L = 547 ft.; B = 71 ft.; Load block coefft. = ·70

$$\beta = \cdot 59 + \frac{5 \cdot 1\ D}{1{,}000{,}000}$$

Class (10): L = 525 ft.; B = 70 ft.; Load block coefft. = ·71

$$\beta = \cdot 60 + \frac{5 \cdot 15\ D}{1{,}000{,}000}$$

Class (11): L = 600 ft.; B = 73 ft.; Load block coefft. = .73

$$\beta = \cdot 607 + \frac{4 \cdot 5\ D}{1{,}000{,}000}$$

Class (12): L = 450 ft.; B = 58 ft.; Load block coefft. = ·74

$$\beta = \cdot 63 + \frac{6 \cdot 9\ D}{1{,}000{,}000}$$

Class (13): L = 400 ft.; B = 52 ft.; Load block coefft. = ·76

$$\beta = .693 + \frac{5{\cdot}9\ D}{1{,}000{,}000}$$

Class (14): L = 480 ft.; B = 58 ft.; Load block coefft. = ·77

$$\beta = \cdot 693 + \frac{4{\cdot}535\ D}{1{,}000{,}000}$$

Class (15): L = 520 ft.; B = 64 ft.; Load block coefft. = ·77

$$\beta = \cdot 693 + \frac{3{\cdot}34\ D}{1{,}000{,}000}$$

In view of the straight line law for the block coefficient, A and b were assumed to vary as a straight line law for ships of similar load block coefficient but of different lengths and breadths. The ratio of the beam to the load draft for the vessels mentioned above varied from 2·0 to 2·8 but the draft could not be included in the formulae as there would have been two unknowns. It was thought that, for approximately the block coefficient at reduced displacements, only the length and breadth should be taken into account. The following are the formulae obtained.

For ships 400 ft. by 58 ft. to 520 ft. by 74 ft. Load β 0·56 to 0·57

$$\beta = \cdot 4044 + \frac{\cdot 926\ \text{L.B.}}{1{,}000{,}000} + \frac{(43{\cdot}5 - \cdot 00092\ \text{L.B.})\ D}{1{,}000{,}000} \quad \text{.....(1 \& 2)}$$

530 ft. by 73 ft. to 630 ft. by 82 ft. Load block coefft. 0·64 to 0·65

$$\beta = \cdot 576 - \frac{1{\cdot}78\ \text{L.B.}}{1{,}000{,}000} + \frac{(9{\cdot}3 - \cdot 00007\ \text{L.B.})\ D}{1{,}000{,}000} \quad \text{.....(3 \& 4)}$$

520 ft. by 71 ft. to 600 ft. by 76 ft. Load block coefft. 0·65 to 0·66

$$\beta = \cdot 5528 - \frac{0{\cdot}7\ \text{L.B.}}{1{,}000{,}000} + \frac{(10{\cdot}325 - \cdot 000104\ \text{L.B.})\ D}{1{,}000{,}000} \quad \text{.....(5 \& 6)}$$

520 ft. by 60 ft. to 600 ft. by 70 ft. Load block coefft. 0·68 to 0·69

$$\beta = \cdot 693 - \frac{3{\cdot}75\ \text{L.B.}}{1{,}000{,}000} + \frac{(5{\cdot}7375 - \cdot 000015\ \text{L.B.})\ D}{1{,}000{,}000} \quad \text{.....(7 \& 8)}$$

520 ft. by 70 ft. to 550 ft. by 71 ft. Load block coefft. 0·70 to 0·71

$$\beta = .776 - \frac{4{\cdot}79\ \text{L. B.}}{1{,}000{,}000} + \frac{(6{\cdot}03 - \cdot 000024\ \text{L.B.})\ D}{1{,}000{,}000} \quad \text{.....(9 \& 10)}$$

450 ft. by 58 ft. to 600 ft. by 73 ft. Load block coefft. 0·73 to 0·74

$$\beta = \cdot 664 - \frac{1{\cdot}3\ \text{L.B.}}{1{,}000{,}000} + \frac{(10{\cdot}45 - \cdot 000136\ \text{L.B.})\ D}{1{,}000{,}000} \quad \text{.....(11 \& 12)}$$

400 ft. by 52 ft. to 520 ft. by 64 ft. Load block coefft. 0·76 to 0·77

$$\beta = \cdot 693 + \frac{(10{\cdot}19 - \cdot 000206\ \text{L.B.})\ D}{1{,}000{,}000} \quad \text{.....(13-15)*}$$

* One term of formula apparently omitted by author.

where, $\beta =$ block coefficient; L = length between perpendiculars; B = moulded breadth; D = displacement in tons.

(4) Definition of Ship's Coefficients.

$$\text{Block coefficient} = \frac{\text{Volume of displacement in cubic feet}}{L \times B \times d} \quad \ldots\ldots (9)$$

$$\text{Prismatic coefficient} = \frac{\text{Volume of displacement in cubic feet}}{(\text{Area of midship section to waterline in square feet}) \times L} \quad \ldots\ldots (10)$$

$$\text{Mid area coefficient} = \frac{\text{Area of midship section to waterline in square feet}}{B \times d} \quad \ldots\ldots (11)$$

$$= \frac{\text{Block coefft.}}{\text{Prismatic coefft.}} \quad \ldots\ldots (12)$$

where, L = length in feet between perpendiculars

B = moulded breadth in feet

d = draught in feet

To approximate the prismatic coefficient at reduced displacements, it is sufficiently near to assume the mid area coefficient constant, since the variation of this coefficient is small in normal ship forms over a wide range of displacement.

(5) Determination of Shaft Horsepower.

The SHP. required to propel the bare hull at any given speed is found by dividing the EHP. by the propulsive efficiency.

$$\text{Propulsive efficiency} = \frac{\text{EHP. bare hull}}{\text{SHP.}} \quad \ldots\ldots (13)$$

$$= \frac{\text{Resistance in pounds} \times V \times \frac{6,080}{60}}{\text{Torque in lb. ft.} \times 2\pi \times \text{revs. per minute}} \quad \ldots\ldots (14)$$

This may be written as follows:—

$$\frac{\text{EHP.}}{\text{SHP.}} = \frac{(R)}{(T)} \frac{(V)}{(V_1)} \frac{(T.V_1)}{(S_1)} \frac{(S_1)}{(S)} \frac{(101{\cdot}33)}{(33,000)} \quad \ldots\ldots (15)$$

$$\text{Now, } \frac{R.V}{T.V_1} = \frac{\text{E.H.P.}}{\text{THP.}} = \text{hull efficiency} = n_H \quad \ldots\ldots (16)$$

$$\frac{101{\cdot}33.T.V_1}{33,000.S_1} = \frac{\text{Thrust horsepower}}{\text{SHP. in open water}} = \text{Screw efficiency in open water} = n_p \quad \ldots\ldots (17)$$

$$\frac{S_1}{S} = \frac{\text{SHP. in open water}}{\text{SHP. behind}} = \text{relative rotative efficiency} = n_r \quad \ldots\ldots (18)$$

$$\therefore \text{ Propulsive efficiency} = n_H n_p n_r \quad \ldots\ldots (19)$$

Where, R = resistance of bare hull in pounds
T = thrust of propellers in pounds
V = speed of ship in knots
V_1 = speed of advance of propellers in knots
S_1 = shaft horsepower at propellers when running in open water
S = shaft horsepower at propellers when running behind ship

From the above, the SHP. required at the propellers for the bare hull without appendages is,

$$\text{SHP.} = \frac{\text{EHP.}}{n_p n_r n_H} \quad \ldots\ldots (20)$$

The hull efficiency (n_H) may be written as follows:—

Suppose

$$T - R = t.T$$

where t is a coefficient called the "thrust deduction factor". Then,

$$\frac{R}{T} = (1 - t) \quad \ldots\ldots (21)$$

Again,

$$\text{Froude's wake factor } w = \frac{V - V_1}{V_1}$$

whence,

$$\frac{V}{V_1} = (1 + w) \quad \ldots\ldots (22)$$

$$\frac{R.V}{T.V_1} = (1 - t)\ (1 + w) \quad \ldots\ldots (23)$$

This fraction is generally in the region of unity, seldom below, and for practical estimating purposes, before tank experiments, may be taken as unity. Also, from a number of tank experiments of liner forms, n_r, the relative rotative efficiency, may be assumed as unity so that the product ($n_H n_r$) called the "qualified hull efficiency" becomes unity. Equation (20) therefore reduces to,

$$\text{SHP. bare hull} = \frac{\text{EHP.}}{n_p} \quad \ldots\ldots (24)$$

To obtain the estimated SHP. required at the thrust block to propel the ship at any given speed, an allowance has to be made for the following:—

(*a*) Appendages—bossing, rudder and bilge keels.
(*b*) Wind resistance.
(*c*) Weather conditions.
(*d*) Friction of shafting.

An allowance on the bare hull EHP. of 5 per cent. will cover (*a*) above, and under trial trip conditions an additional 10 per cent will cover (*b*) and (*c*).

For round voyage conditions, for Eastern-going liners, a total allowance for (*a*) (*b*) and (*c*) of 29 per cent has been found in practice to be adequate.

In modern liners, self-lubricated tunnel shafting bearings are installed which reduce the frictional losses between the thrust block and propellers to about 1 per cent. Hence, for estimating purposes,

$$\text{Trial SHP.} = \frac{\text{EHP. bare hull} + 15\%}{\cdot 99 n_p} \quad \ldots\ldots (25)$$

$$\text{Voyage SHP.} = \frac{\text{EHP. bare hull} + 29\%}{\cdot 99 n_p} \quad \ldots\ldots (26)$$

where "EHP. bare hull" applies to the respective trial and voyage displacements at any given speed.

(6) On the Estimation of "n_p", the Open Water Efficiency of a Screw Propeller.

A complete investigation into the experimental work of Froude, Taylor, Durand and Schaffron on propellers was made by Admiral D. W. Taylor of the United States Navy in 1924 and the series of curves shown in *Figs. 1 and 1A were put forward embodying the work of these four great authorities. The data is given in the form of dimensionless constants, the abscissa being a constant B_p based upon three factors which are always known in the early stages of the design, namely,

Propeller revolutions per minute ..... N
Shaft horsepower at propeller ..... S
Speed of advance through wake water ..... V_1

$$\text{Power coefficient } B_p = \frac{N.S^{\frac{1}{2}}}{V_1^{2 \cdot 5}} \quad \ldots\ldots (27)$$

The curves show the efficiency, pitch ratio and diameter constant δ, where,

$$\delta = \frac{N.D.}{V_1}$$

a function of pitch ratio and real slip.

$$\text{Real slip } (s) = \frac{p.N - V_1 \times 101{\cdot}33}{p.N.}$$

Whence,

$$N = \frac{V_1 \times 101{\cdot}33}{p\ (1-s)}$$

$$\delta = \frac{V_1 \times 101{\cdot}33\ D}{p.V_1\ (1-s)} = \frac{101{\cdot}33}{\frac{p}{D}\ (1-s)} \quad \ldots\ldots (28)$$

where, $\frac{p}{D}$ = pitch ratio.

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*Figures 1 and 1A reproduced by kind permission of Dr. G. S. Baker from his book "Ship Design, Resistance and Screw Propulsion".

Before Figs. 1 and 1A can be used for designing the propeller and obtaining its open water efficiency, it is necessary to approximate the SHP. at the required speed. The method is as follows:—

(*a*) Calculate the EHP. on the given displacement and speed.

(*b*) Assume n_H 1·0 and $n_r = 1{\cdot}0$.

(*c*) From similar types of twin screw ships, assume n_p at say 66%.

(*d*) V_1 from similar ships may be taken as $\frac{V}{1{\cdot}20}$

(*e*) B_p can now be calculated.

(*f*) Lift off from diagram 1 the efficiency and pitch ratio at various values of δ.

(*g*) Draw curves of δ and efficiency on a base of pitch ratio.

(*h*) Select the best propeller and lift off efficiency from curve.

(*i*) SHP. on trial $= \frac{\text{EHP.} + 15\%}{\cdot 99 n_p}$

(*j*) SHP. at sea $= \frac{\text{EHP.} + 29\%}{\cdot 99 n_p}$

From the above basic discussion, the EHP. and SHP. will be calculated at the estimated trial, service and load displacements for a vessel having the following dimensions.

(7) Ship Dimensions.

Length between perpendiculars	530 ft. 0 in.
Length on waterline	550 ft. 0 in.
Moulded beam	73 ft. 0 in.
Load draft	29 ft. 6 in.
Load block coefficient	0·650
Load prismatic coefficient	0·670
Sea speed	19¼ knots on load displacement

$$\text{Load displacement} = \frac{530 \times 73{\cdot}0 \times 29{\cdot}5 \times {\cdot}65}{35} = 21{,}190 \text{ tons}$$

$$\text{Beam draft ratio} = \frac{73}{29{\cdot}5} = 2{\cdot}474$$

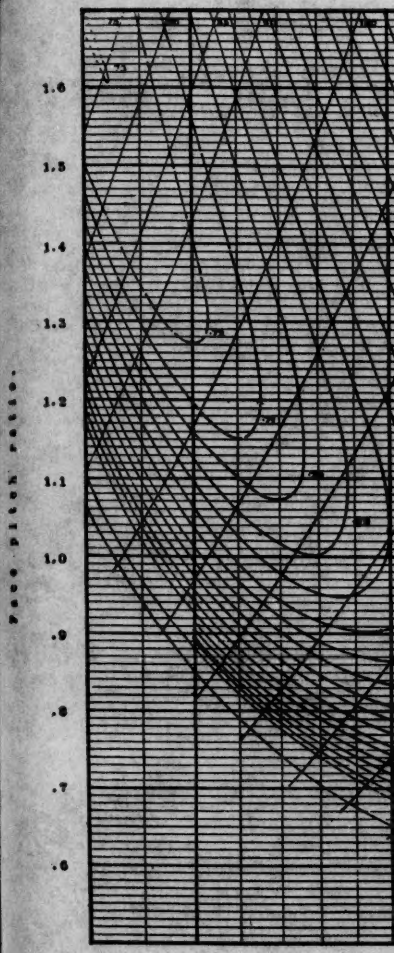
$$\text{Displacement length ratio} = \frac{21{,}190}{\left(\frac{550}{100}\right)^3} = 127{\cdot}3$$

Taylor's formula

$$S = 16{\cdot}25 \sqrt{21{,}190 \times 550} = 55{,}500 \text{ sq. ft.}$$

Denny's formula

$$S = 1{\cdot}86 \times 550 \times 29{\cdot}5 + \frac{21{,}190 \times 35}{29{\cdot}5} = 55{,}300 \text{ sq. ft.}$$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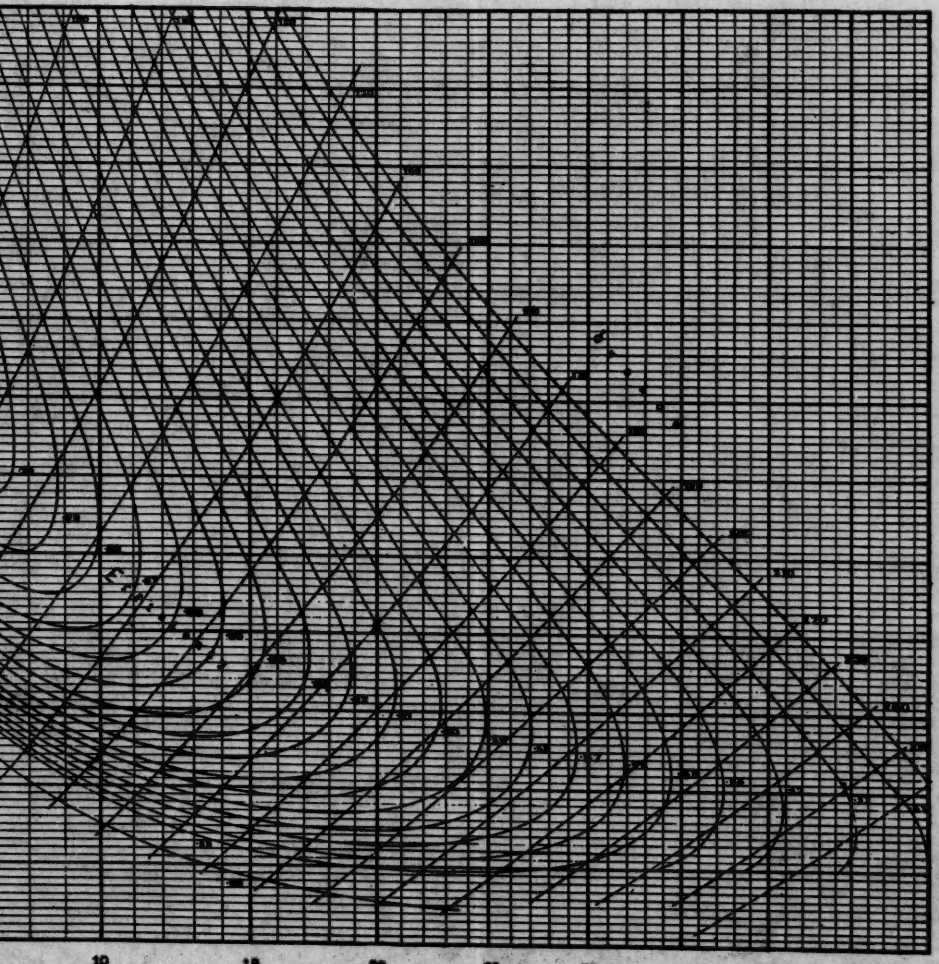
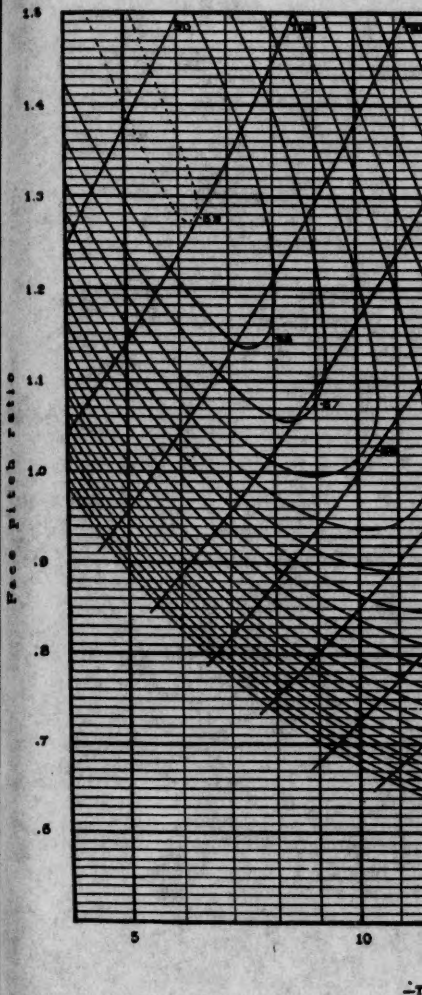


—Taylor's B_p Diagram for Three-bladed Screws. Circular back. b.t.f. = -05. m.w.r. = -35. Elliptic outline.

$B_p = \frac{N\sqrt{S}}{V_1^{2.5}}$ $\delta = \frac{N \cdot D}{V_1}$ where $\begin{cases} S = \text{shaft horse-power}, & V_1 = \text{wake speed in knots} = \left(\frac{V}{1+w}\right) \\ N = \text{revs. per minute}, & D = \text{diameter in feet.} \end{cases}$

Fig. 1.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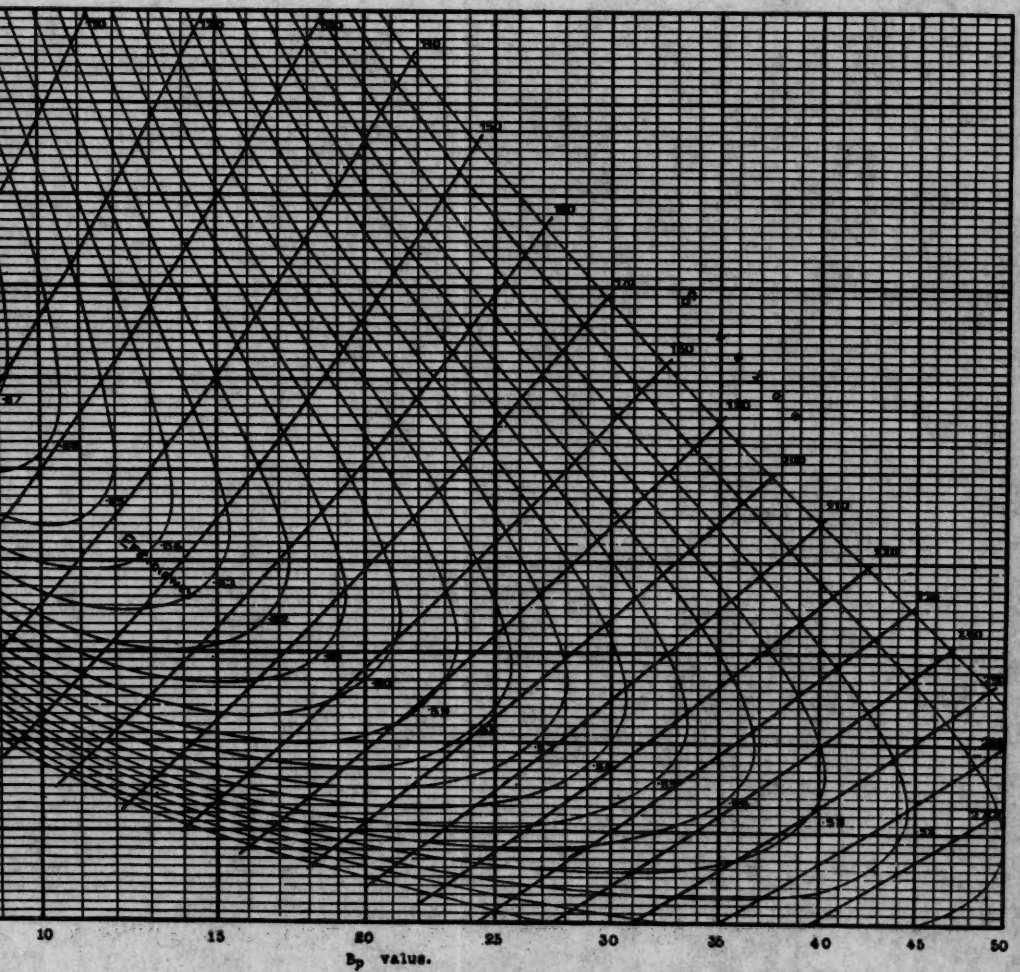
Face pitch ratio
5
10



—Taylor's B_p Diagram for Four-bladed Screws. Circular back. b.t.f. = ·05. a.w.r. = ·25. Elliptic outline.

$B_p = \frac{N S^{0.5}}{V_1^{2.5}}$ $\delta = \frac{N D}{V_1}$ where $\begin{cases} S = \text{shaft horse-power}, & V_1 = \text{wake speed in knots} = \left(\frac{V}{1+w}\right) \\ N = \text{revs. per minute}, & D = \text{diameter in feet} \end{cases}$

Fig. 1A.

Froude's formula

$$S = (21{,}190 \times 35)^{\frac{2}{3}}\left(3{\cdot}7 + \frac{550}{2 \times (21{,}190 \times 35)^{\frac{1}{3}}}\right)$$

$$= 8{,}200 \times 6{\cdot}74$$

$$= 55{,}270 \text{ sq. ft.}$$

The mean of the three calculations may be taken as 55,400 sq. ft. and the resistance will be calculated on this.

"f" from Table 1 above = ·00875

(8) Calculation of EHP. on Load Displacement.

The following table gives the residuary resistance in pounds per ton of displacement for the complete speed range of the vessel. Columns 3 and 4 are taken direct from D. W. Taylor's book "Speed and Power of Ships" and column 5 shows the correction for the actual beam-draft ratio.

TABLE 2.

$\frac{V}{\sqrt{L}}$	V	*Beam draft*	*Beam draft*	*Beam draft*
	Knots	3·75	2·25	2·474
		R_r	R_r	R_r
·6	14·04	1·005	0·61	0·6685
·65	15·22	1·280	0·85	0·9136
·70	16·40	1·630	1·155	1·2253
·75	17·55	2·110	1·70	1·7607
·80	18·73	2·720	2·40	2·4474
·85	19·92	3·800	3·15	3·2462
·90	21·08	5·45	4·80	4·8962
·95	22·25	8·35	8·35	8·35

The frictional resistance per ton of displacement is worked out for each of the above speeds and added to column 5 above to obtain R_t, the total resistance per ton of displacement from which the EHP. is at once determined from equation 7 above.

$$\frac{V}{\sqrt{L}} = ·6. \quad R_f = \frac{f.S.V^{1·83}}{D} = \frac{·00875 \times 55{,}400 \times 14·04^{1·83}}{21{,}190}$$

$$= ·022876 \times 14·04^{1·83} = 2·91 \text{ lb./ton}$$

R_r ..... $= 0·6685$ "

R_t ..... $= 3·5785$ "

$$\text{EHP.} = ·0030707 \times 21{,}190 \times 3·5785 \times 14·04 = 3{,}260$$

$$\frac{V}{\sqrt{L}} = ·65. \quad R_f = ·022876 \times 15·22^{1·83} \text{.....} = 3·343 \text{ lb./ton}$$

R_r ..... $= 0·9136$ "

R_t ..... $= 4·2566$ "

$$\text{EHP.} = ·0030707 \times 21{,}190 \times 4·2566 \times 15·22 = 4{,}215$$

$\frac{V}{\sqrt{L}} = \cdot 70$. $R_f = \cdot 022876 \times 16 \cdot 40^{1 \cdot 83}$ ..... $= 3 \cdot 82$ lb./ton

R_r ..... $= 1 \cdot 2253$ "

R_t ..... $= 5 \cdot 0453$ "

EHP. $= \cdot 0030707 \times 21,190 \times 5 \cdot 0453 \times 16 \cdot 40 = 5,375$

$\frac{V}{\sqrt{L}} = \cdot 75$. $R_f = \cdot 022876 \times 17 \cdot 55^{1 \cdot 83}$ ..... $= 4 \cdot 4$ lb./ton

R_r ..... $= 1 \cdot 7607$ "

R_t ..... $= 6 \cdot 1607$ "

EHP. $= \cdot 0030707 \times 21,190 \times 6 \cdot 1607 \times 17 \cdot 55 = 7,030$

$\frac{V}{\sqrt{L}} = \cdot 80$. $R_f = \cdot 022876 \times 18 \cdot 73^{1 \cdot 83}$ ..... $= 4 \cdot 925$ lb./ton

R_r ..... $= 2 \cdot 4474$ "

R_t ..... $= 7 \cdot 3724$ "

EHP. $= \cdot 0030707 \times 21,190 \times 7 \cdot 3724 \times 18 \cdot 73 = 8,990$

$\frac{V}{\sqrt{L}} = \cdot 85$. $R_f = \cdot 022876 \times 19 \cdot 92^{1 \cdot 83}$ ..... $= 5 \cdot 500$ lb./ton

R_r ..... $= 3 \cdot 2462$ "

R_t ..... $= 8 \cdot 7462$ "

EHP. $= \cdot 0030707 \times 21,190 \times 8 \cdot 7462 \times 19 \cdot 92 = 11,330$

$\frac{V}{\sqrt{L}} = \cdot 90$. $R_f = \cdot 022876 \times 21 \cdot 08^{1 \cdot 83}$ ..... $= 6 \cdot 070$ lb./ton

R_r ..... $= 4 \cdot 8962$ "

R_t ..... $= 10 \cdot 9662$ "

EHP. $= \cdot 0030707 \times 21,190 \times 10 \cdot 9662 \times 21 \cdot 08 = 15,020$

(9) Calculation of EHP. on Average Estimated Voyage Displacement of 16,500 tons.

(*a*) Estimated block coefficient at 16,500 tons displacement from formulae (3-4) above.

$$\beta = \cdot 576 - \frac{1 \cdot 78 \times 530 \times 73}{1,000,000} + \frac{(9 \cdot 3 - \cdot 00007 \times 530 \times 73)\ 16,500}{1,000,000}$$

$= \cdot 5071 + \cdot 1087$

$= \cdot 6158$, say $\cdot 616$

(*b*) Estimated draft on 16,500 tons displacement.

$$\text{Draft} = \frac{35 \times 16,500}{530 \times 73 \times \cdot 616} = 24 \cdot 22 \text{ feet.}$$

(*c*) Beam draft ratio $= \frac{73}{24{\cdot}22} = 3{\cdot}008$

prismatic coefft. $\frac{{\cdot}616}{{\cdot}97} = {\cdot}635$

(*d*) Displacement/length coefft. $= 99{\cdot}5$

TABLE 3.

$\frac{V}{\sqrt{L}}$	V Knots	*Beam draft* (3·75) R_r	*Beam draft* 2·25 R_r	*Beam draft* 3·008 R_r
·60	14·04	·900	·54	0·722
·65	15·22	1·120	·745	0·9345
·70	16·40	1·370	·980	1·177
·75	17·55	1·73	1·37	1·552
·80	18·73	2·22	1·88	2·052
·85	19·92	2·92	2·48	2·702
·90	21·08	4·25	3·67	3·963

Wetted surface $= 16{\cdot}25\ \sqrt{16{,}500 \times 550} = 48{,}900$ sq. ft.

Denny's formula:

$$S = 1{\cdot}86 \times 550 \times 24{\cdot}22 + \frac{16{,}500 \times 35}{24{\cdot}22} = 48{,}600 \text{ sq. ft.}$$

Froude's formula:

$$S = (16{,}500 \times 35)^{\frac{2}{3}} \left(3{\cdot}7 + \frac{550}{2(16{,}500 \times 35)^{\frac{1}{3}}}\right) = 48{,}500 \text{ sq. ft.}$$

Taking the mean of these three, wetted surface $= 48{,}667$ sq. ft.

$$\frac{V}{\sqrt{L}} = {\cdot}6. \quad R_f = \frac{f.S.V^{1{\cdot}83}}{D} = \frac{{\cdot}00875 \times 48{,}667 \times V^{1{\cdot}83}}{16{,}500} = {\cdot}0258\ V^{1{\cdot}83}$$

$R_f = {\cdot}0258 \times 14{\cdot}04^{1{\cdot}83}$ ..... $= 3{\cdot}28$ lb./ton
R_r ..... $= {\cdot}722$ "
R_t ..... $= 4{\cdot}002$ "

EHP. $= {\cdot}0030707 \times 16{,}500 \times 4{\cdot}002 \times 14{\cdot}04 = 2{,}853$

$\frac{V}{\sqrt{L}} = {\cdot}65$. $R_f = {\cdot}0258 \times 15{\cdot}22^{1{\cdot}83}$ ..... $= 3{\cdot}765$ lb./ton

R_r ..... $= {\cdot}9345$ "
R_t ..... $= 4{\cdot}6995$ "

EHP. $= {\cdot}0030707 \times 16{,}500 \times 4{\cdot}6995 \times 15{\cdot}22 = 3{,}622$

$\frac{V}{\sqrt{L}} = \cdot 70$. $R_f = \cdot 0258 \times 16{\cdot}4^{1\cdot 83}$ ..... $= 4.31$ lb./ton

R_r ..... $= 1{\cdot}177$ "

R_t ..... $= 5{\cdot}487$ "

EHP. $= 0030707 \times 16{,}500 \times 5{\cdot}487 \times 16{\cdot}4 = 4{,}560$

$\frac{V}{\sqrt{L}} = \cdot 75$. $R_f = \cdot 0258 \times 17{\cdot}55^{1\cdot 83}$ ..... $= 4{\cdot}950$ lb./ton

R_r ..... $= 1{\cdot}552$ "

R_t ..... $= 6{\cdot}502$ "

EHP. $= \cdot 0030707 \times 16{,}500 \times 6{\cdot}502 \times 17{\cdot}55 = 5{,}790$

$\frac{V}{\sqrt{L}} = \cdot 80$. $R_f = \cdot 0258 \times 18{\cdot}73^{1\cdot 83}$ ..... $= 5{\cdot}55$ lb./ton

R_r ..... $= 2{\cdot}052$ "

R_t ..... $= 7{\cdot}602$ "

EHP. $= \cdot 0030707 \times 16{,}500 \times 7{\cdot}602 \times 18{\cdot}73 = 7{,}220$

$\frac{V}{\sqrt{L}} = \cdot 85$. $R_f = \cdot 0258 \times 19{\cdot}92^{1\cdot 83}$ ..... $= 6{\cdot}200$ lb./ton

R_r ..... $= 2{\cdot}702$ "

R_t ..... $= 8{\cdot}902$ "

EHP. $= \cdot 0030707 \times 16{,}500 \times 8{\cdot}902 \times 19{\cdot}92 = 9{,}000$

$\frac{V}{\sqrt{L}} = \cdot 90$. $R_f = \cdot 0258 \times 21{\cdot}08^{1\cdot 83}$ ..... $= 6{\cdot}845$ lb./ton

R_r ..... $= 3{\cdot}963$ "

R_t ..... $= 10{\cdot}808$ "

EHP. $= \cdot 0030707 \times 16{,}500 \times 10{\cdot}808 \times 21{\cdot}08 = 11{,}560$

(10) Calculation of EHP. on Estimated Trial Displacement of 15,000 tons.

Block coefft.

$$= \cdot 576 - \frac{1{\cdot}78 \times 530 \times 73}{1{,}000{,}000} + \frac{(9{\cdot}3 - \cdot 00007 \times 530 \times 73)\ 15{,}000}{1{,}000{,}000}$$

$= \cdot 5071 + \cdot 0987$

$= \cdot 6058$, say $\cdot 606$

Prismatic coefft. $= \frac{\cdot 606}{\cdot 97} = \cdot 625$

Draft at 15,000 tons displ. $= \frac{35 \times 15{,}000}{530 \times 73 \times \cdot 606} = 22{\cdot}4$ feet

Beam-draft ratio $= \frac{73}{22{\cdot}4} = 3{\cdot}26$

Displacement length coefficient $= \frac{D}{\left(\frac{L}{100}\right)^3} = \frac{15{,}000}{(5{\cdot}5)^3} = 90{\cdot}4$

TABLE 4.

$\frac{V}{\sqrt{L}}$	V	*Beam draft* 3·75 R_r	*Beam draft* 2·25 R_r	*Beam draft* 3·26 R_r
	Knots			
·60	14·04	·87	·51	·750
·65	15·22	1·07	·70	·946
·70	16·40	1·30	·94	1·180
·75	17·55	1·62	1·30	1·513
·80	18·73	2·125	1·73	1·993
·85	19·92	2·75	2·30	2·600
·90	21·08	3·95	3·40	3·766

Wetted Surface.

Taylor's formula

$= 16{\cdot}25\sqrt{15{,}000 \times 550} = 46{,}600$ sq. ft.

Denny's formula

$= 1{\cdot}86 \times 550 \times 22{\cdot}4 + \frac{15{,}000 \times 35}{22{\cdot}4} = 46{,}320$ sq. ft.

Froude's formula

$= (15{,}000 \times 35)^{\frac{2}{3}}\left(3{\cdot}7 + \frac{550}{2\,(15{,}000 \times 35)^{\frac{1}{3}}}\right) = 46{,}250$ sq. ft.

Mean wetted surface = 46,390 sq. ft.

$\frac{V}{\sqrt{L}} = \cdot 60$. $R_t = \frac{\cdot 00875 \times 46{,}390 V^{1\cdot 83}}{15{,}000} = \cdot 02702 V^{1\cdot 83}$

$R_t = \cdot 02702 \times 14{\cdot}04^{1\cdot 83}$ ..... $= 3{\cdot}44$ lb./ton

R_r ..... $= \cdot 75$ "

R_t ..... $= 4{\cdot}19$ "

EHP. $= \cdot 0030707 \times 15{,}000 \times 4{\cdot}19 \times 14{\cdot}04 = 2{,}710$

$\frac{V}{\sqrt{L}} = \cdot 65$. $R_t = \cdot 02702 \times 15{\cdot}22^{1\cdot 83}$ ..... $= 3{\cdot}945$ lb./ton

R_r ..... $= \cdot 946$ "

R_t ..... $= 4{\cdot}891$ "

EHP. $= \cdot 0030707 \times 15{,}000 \times 4{\cdot}891 \times 15{\cdot}22 = 3{,}425$

$\frac{V}{\sqrt{L}} = \cdot 70$. $R_f = \cdot 02702 \times 16{\cdot}40^{1\cdot 83}$ ..... $= 4{\cdot}51$ lb./ton

R_r ..... $= 1{\cdot}18$ "

R_t ..... $= 5{\cdot}69$ "

EHP. $= \cdot 0030707 \times 15{,}000 \times 5{\cdot}69 \times 16{\cdot}40 = 4{,}300$

$\frac{V}{\sqrt{L}} = \cdot 75$. $R_f = \cdot 02702 \times 17{\cdot}55^{1\cdot 83}$ ..... $= 5{\cdot}195$ lb./ton

R_r ..... $= 1{\cdot}513$ "

R_t ..... $= 6{\cdot}708$ "

EHP. $= \cdot 0030707 \times 15{,}000 \times 6{\cdot}708 \times 17{\cdot}55 = 5{,}440$

$\frac{V}{\sqrt{L}} = \cdot 80$. $R_f = \cdot 02702 \times 18{\cdot}73^{1\cdot 83}$ ..... $= 5{\cdot}810$ lb./ton

R_r ..... $= 1{\cdot}993$ "

R_t ..... $= 7{\cdot}803$ "

EHP. $= \cdot 0030707 \times 15{,}000 \times 7{\cdot}803 \times 18{\cdot}73 = 6{,}750$

$\frac{V}{\sqrt{L}} = \cdot 85$. $R_f = \cdot 02702 \times 19{\cdot}92^{1\cdot 83}$ ..... $= 6{\cdot}495$ lb./ton

R_r ..... $= 2{\cdot}600$ "

R_t ..... $= 9{\cdot}095$ "

EHP. $= \cdot 0030707 \times 15{,}000 \times 9{\cdot}095 \times 19{\cdot}92 = 8{,}360$

$\frac{V}{\sqrt{L}} = \cdot 90$. $R_f = \cdot 02702 \times 21{\cdot}08^{1\cdot 83}$ ..... $= 7{\cdot}170$ lb./ton

R_r ..... $= 3{\cdot}766$ "

R_t ..... $= 10{\cdot}936$ "

EHP. $= \cdot 0030707 \times 15{,}000 \times 10{\cdot}936 \times 21{\cdot}08 = 10{,}630$

(11) Summary of EHP. Values.

Tables 5 and 6 below give the values of the EHP. for the three displacements.

TABLE 5.

$\frac{V}{\sqrt{L}}$	V knots	E.H.P. Displacement tons. 15,000	16,500	21,190
·60	14·04	2,710	2,853	3,260
·65	15·22	3,425	3,622	4,215
·70	16·40	4,300	4,560	5,375
·75	17·55	5,440	5,790	7,030
·80	18·73	6,750	7,220	8,990
·85	19·92	8,360	9,000	11,330
·90	21·08	10,630	11,560	15,020

The results given in Table 5 are plotted in Figure 2 from which the EHP. at each half knot has been lifted and is given in Table 6.

TABLE 6.

$\frac{V}{\sqrt{L}}$	V knots	E.H.P. Displacement tons 15,000	16,500	21,190
0·575	14	2,700	2,800	3,220
0·619	14·5	3,000	3,150	3,620
0·640	15	3,300	3,490	4,030
0·662	15·5	3,640	3,850	4,450
0·683	16	4,000	4,230	4,940
0·7045	16·5	4,380	4,640	5,500
0·725	17	4,860	5,150	6,160
0·747	17·5	5,350	5,690	6,910
0·769	18	5,860	6,260	7,740
0·790	18·5	6,530	6,870	8,580
0·810	19	7,100	7,530	9,450
0·820	19·25	7,450		9,900
0·8315	19·5	7,800	8,270	10,420
0·854	20·0	8,550	9,150	11,550
0·875	20·5	9,430	10,150	13,000
0·895	21·0	10,450	11,330	14,880
0·917	21·5	11,700	12,870	17,250

(12) Calculation of SHP. on Load Displacement.

As pointed out earlier, before Figures 1 or 1A can be used for designing the propeller, an estimate of the shaft horsepower to be absorbed has to be made as outlined under the foregoing headings (*a*) to (*j*).

Assuming from known data of existing twin-screw vessels an open water propeller efficiency of 66 per cent., the estimated shaft horsepower required at sea to maintain 19¼ knots on load displacement is,

$$\text{SHP.} = \frac{9{,}900 \times 1{\cdot}29}{{\cdot}66 \times {\cdot}99} = 19{,}750$$

$$= 9{,}875 \text{ SHP. each propeller}$$

Propeller revolutions per minute = 125

$$\text{Speed of advance } V_1 = \frac{19{\cdot}25}{1{\cdot}20} = 16{\cdot}04 \text{ knots}$$

$$\text{Power coefficient } B_P = \frac{N.S^{\frac{1}{2}}}{V_1^{2{\cdot}5}} = \frac{125 \times 9{,}875^{\frac{1}{2}}}{16{\cdot}04^{2{\cdot}5}} = 11{\cdot}93$$

From Fig. 1, the following have been lifted:—

δ	*Pitch ratio.*	*Efficiency* %
167	·625	50
160	·700	58·4
150	·808	64·3
140	·940	66·7
130	1·115	66·2
120	1·323	63·5
110	1·600	59·0

From the curve of δ and efficiency plotted on pitch ratio, Figure 1B, an efficiency of 66·9 per cent is shown for a pitch ratio of ·98 and δ value of 137·5,

Hence,

$$\text{Diameter} = \frac{\delta . V_1}{N} = \frac{137{\cdot}5 \times 16{\cdot}04}{125} = 17{\cdot}63 \text{ ft.}$$

$$\text{Face pitch} = {\cdot}98 \times 17{\cdot}63 = 17{\cdot}30 \text{ ft.}$$

$$\text{Developed surface} = {\cdot}04 \times {\cdot}7854 \times 17{\cdot}63^2 = 97{\cdot}8 \text{ sq. ft.}$$

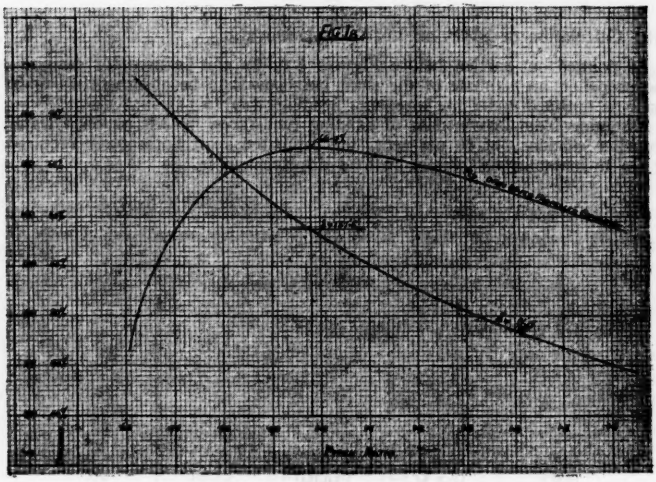


FIG. 1B.

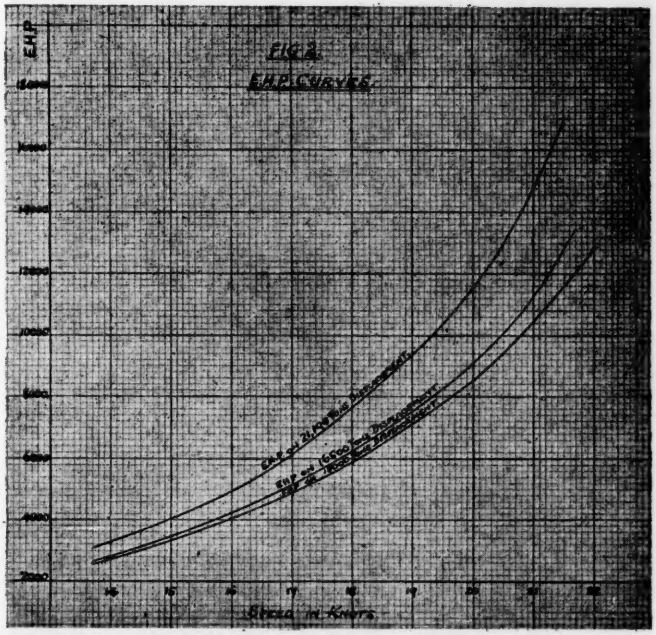


FIG. 2.

Dimensions of Propeller made as follows.

Diameter	17′ - 9″
Mean pitch	17·4 ft.
Developed surface	99 sq. ft.
Number of blades	3
Pitch ratio	0·98
Disc area ratio	0·40
Open water efficiency	66·9% = η_o

SHP. each screw at 19¼ knots on load displacement

$$= \frac{9{,}900 \times 1{\cdot}29}{{\cdot}669 \times {\cdot}99 \times 2} = 9{,}650$$

$$\text{Total SHP.} = 2 \times 9{,}650 = 19{,}300$$

Design machinery for 19,500 SHP.

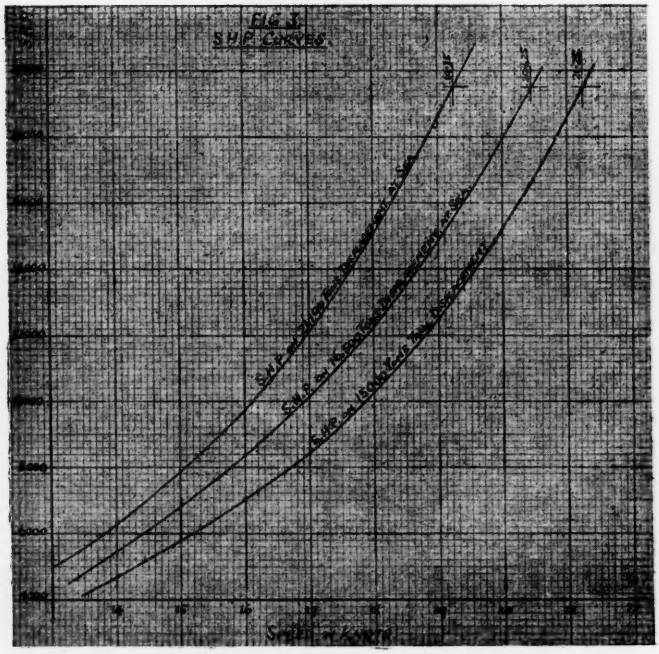


FIG. 3.

Estimated Maximum Trial Speed.

Assuming that the propeller efficiency remains constant, the EHP. may be calculated and the speed lifted off the EHP. curve. Thus
EHP. on 15,000 tons trial conditions

$$= \frac{\cdot 669 \times \cdot 99 \times 19{,}500}{1 \cdot 15} = 11{,}090$$

From the curve of EHP. maximum trial speed = 21¼ knots.

Estimated Maximum Sea Speed.

EHP. on 16,500 tons sea conditions

$$= \frac{\cdot 669 \times \cdot 99 \times 19{,}500}{1 \cdot 29} = 10{,}000$$

From EHP. curve 10,000 EHP. corresponds to 20·425 knots.

(13) Summary of SHP. Values.

Table 7 below gives the values of the shaft horsepower for the three displacements.

TABLE 7.

$\frac{V}{\sqrt{L}}$ knots	Estimated s.h.p.		
	15,000 tons trial	16,500 tons at sea	21,190 tons at sea
14	4,750	5,510	6,350
14½	5,280	6,205	7,130
15	5,805	6,880	7,940
15½	6,400	7,590	8,750
16	7,050	8,340	9,730
16½	7,710	9,150	10,810
17	8,555	10,150	12,130
17½	9,400	11,190	13,610
18	10,310	12,340	15,230
18½	11,500	13,540	16,890
19	12,500	14,820	18,600
19¼			19,500
19½	13,710	16,300	
20	15,050	18,000	
20·425		19,500	
20½	16,600		
21	18,400		
21¼	19,500		

Figure 3 shows the shaft horse-powers at the three displacements.

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WELDING IN SHIPBUILDING.

The following paper by David Arnott, Vice-President and Chief Surveyor, American Bureau of Shipping, New York, N. Y., was presented at the Annual Meeting of the American Welding Society in Cleveland, Ohio, October 21 to 25, 1940. It presents a concise review of the development of welding in shipbuilding and of the present extent of its application. This paper is reprinted from the November, 1940, issue of The Welding Journal published by the American Welding Society, 33 West 39th St., New York, N. Y.

The development of ship construction provides a very interesting study. In the wood ship era Naval Architecture was an art rather than a science and there were definite limitations to the use of wood as a material of construction even when sound and properly seasoned timber in long lengths was readily available. It was impossible to work in sufficient fastenings to develop the full strength of the material and a proper shift of butts, i.e., keeping the plank ends well clear of one another, was essential for structural efficiency. Under stress of weather in heavy seas the wood ship creaked

and groaned and its constituent parts tended to move relatively to one another and to force out the oakum from the caulked seams necessitating periodic recaulking to keep the ship even reasonably tight. In time, the ends of the ship tended to droop as also the bilges. In shipbuilding parlance, the vessels hogged considerably, a hog of three or four feet in old wood ships after a period of service being not unusual. Under such conditions it was no wonder that the largest wood ships built were around 300 feet in length with easy proportions of length to depth, an L/D ratio of about 10. Applying scientific principles to the analysis of the structural strength of these old wood ships one is forced to conclude that relatively too much material was piled in the bottom structure, presumably in support of the fetish that the keel was "the backbone of the ship" and too little material on the deck which constitutes the top flange of the hull girder. However, one has got to hand it to these early builders of wood ships who by rule-of-thumb methods based on experience and the exercise of considerable resource and ingenuity were able to build seaworthy ships out of the material of construction then available.

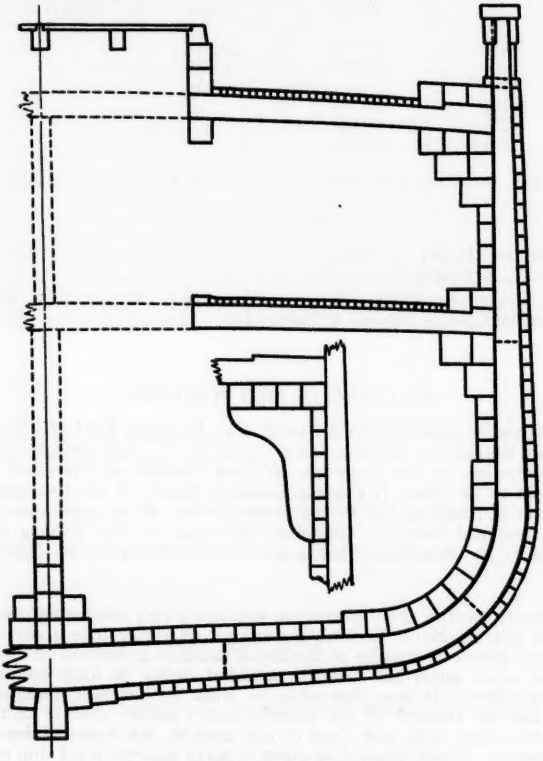


Fig. 1—Midship Section Wood Steamer

Figure 1 shows a midship section of a Ferris type wood steamer of which so many were built during the World War. These ships passed out of the picture very quickly after emergency was over as they were uneconomical in operation and could not compete with the steel ship. It is impossible to show in the diagram the nature and extent of the numerous fastenings holding the various timbers together such as through bolts, edge bolts, treenails and spikes.

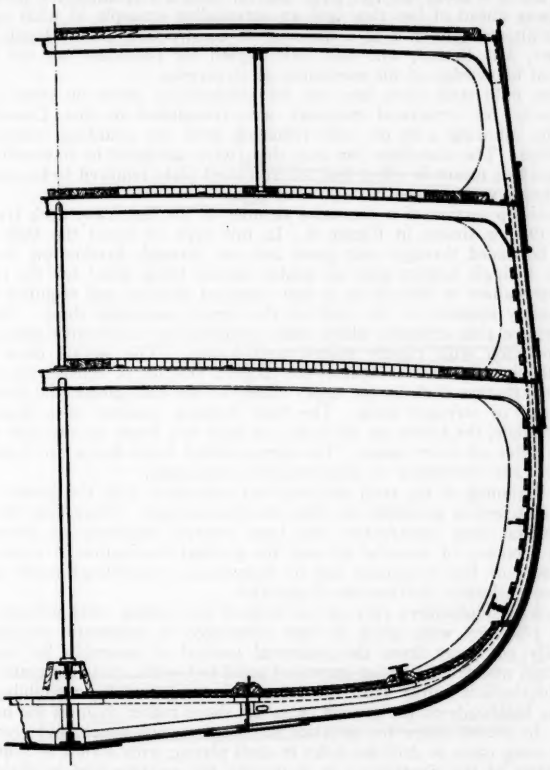


Fig. 2—Midship Section Coastwise Steamer Hurricane Deck Type

When iron ships came to be built it was almost inevitable and certainly human that some of the practices inherent to wood ship design should be continued and the fullest advantage of the infinitely superior material from a structural strength point of view was not taken for many years to come. Too much emphasis was still placed on the bottom structure as was evidenced by the number of heavy keelsons usually fitted. Continuity of such struc-

tural members as keelsons and side stringers through watertight bulkheads was considered essential and necessitated the fitting of numerous and costly smithwelded watertight angle collars and staples. Obtainable iron plates were comparatively narrow and short, resulting in large numbers of seams and butts with plenty of riveting. A bar keel was a common feature of these iron ships and the various parts of the ship's structure including the bulkheads were assembled piece by piece and plate by plate on the ways. The *Great Eastern* about 680 feet long, built in 1858, a Leviathan for those days, was away ahead of her time and an outstanding example of what could be done with wrought iron as a material of construction, in the hands of her designer, Mr. Brunel, who had little regard for precedent but did have a practical knowledge of the mechanics of structures.

When mild steel came into use for shipbuilding about 60 years ago its superiority for structural purposes was recognized by the Classification Societies allowing a 20 per cent reduction from the scantlings required for iron ships. The scantlings for iron ships were tabulated in sixteenths of an inch and this meant in effect that an iron shell plate required to be, say, 8/16 in thickness was accepted at 8/20 if of steel.

A midship section of a coastwise steamer of the hurricane deck type built about 1900 is shown in Figure 2. In this type of vessel the bulk of the cargo is loaded through side ports and not through hatches on the deck. This is a single bottom ship, no double bottom being fitted for the carriage of water ballast or fuel oil as is now common practice and required by law as a safety measure in the case of the larger passenger ships. Note the cumbersome side stringers which were comparatively ineffective unless fitted in association with closely spaced web frames. The second deck is the strength or main deck as against the modern practice of considering the top or superstructure deck as the upper flange of the hull girder and making it the heavy or strength deck. The hold framing consists of a frame and reverse angle, the beams on all decks are bulb tees fitted on alternate frames with a pillar on every beam. The forge-welded beam knees are interesting and were the forerunner of plate bracket connections.

The beginning of the steel ship era was coincident with the general application of scientific principles to ship structural design. Since then the trend in merchant ship construction has been toward simplicity of design and greater economy of material through the gradual elimination of parts which were more or less redundant and by reductions in scantlings made possible by a more effective distribution of material.

American shipbuilders ever on the lookout for cutting costs without sacrifice of efficiency were quick to take advantage of pneumatic riveting and gradually got away from the piecemeal method of assembly by improved production methods involving increased mold loft work, plate templates being made in the loft rather than lifted from the ship and by assembling such items as bulkheads on the ground or in the shops rather than on the building ways. In recent years the practice has been to sub-punch and ream and even in some cases to drill the holes in shell plating with a view to improving the quality of the riveting as it is usually the riveting and caulking that gives trouble in service, the renewal of leaky or corroded rivets being a source of considerable expense to an owner throughout the life of the ship.

A midship section of a modern riveted cargo ship is shown in Figure 3 and a comparison with Figure 2 will show the trend of development in ship structural design. The frames and beams are channels joggled in order to eliminate the necessity of fitting liners in way of outside strakes of plating. Wide-spaced pillars are fitted at the center line in association with deck girders and no side stringers are fitted. In the double bottom solid floors are fitted on every third frame, the intermediate open floors providing

easy access for tank examination and cleaning. Relatively wide shell plates are used in order to cut down the amount of riveting. As compared with Figure 2 the relatively clear space provided for cargo in order to minimize broken stowage is apparent. With maximum joint efficiencies for riveted end connections in the order of about 75 per cent, good design still requires an effective shift of butts in the strakes of plating especially of the shell and strength deck.

It is a fact that prior to the general use of arc welding we had reached such a high degree of efficiency in the design and construction of riveted ships as a result of the application of scientific principles to their design and of the experience gained through close observation of ships under service

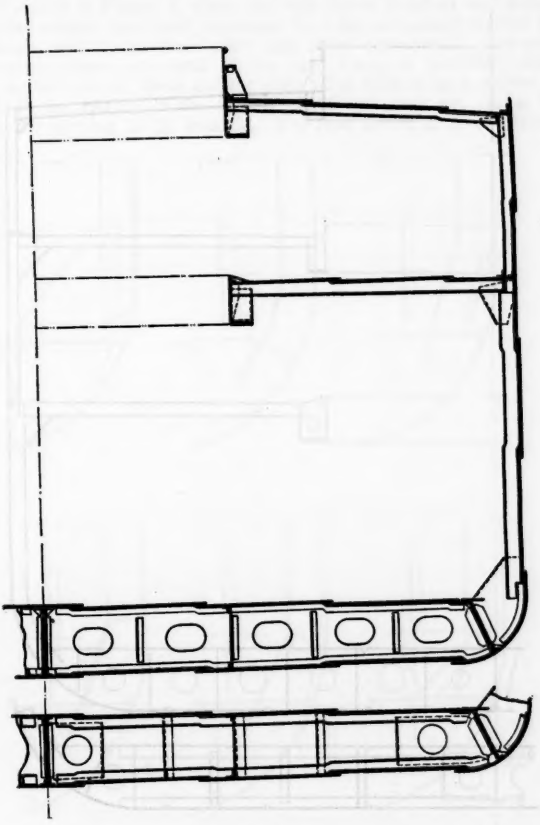


Fig. 3—Midship Section Modern Riveted Cargo Ship

conditions that it was becoming increasingly difficult to conceive how any further major reductions in scantlings or improvements in structural design could properly be effected without the general adoption of special and more expensive steels.

The application of welding to ship construction has opened up an entirely new vista providing as it does a new tool for the production of more efficient and more economical hull structures. The earlier welded ships were, as one would expect, merely riveted designs welded so that economy from the use of the new process was not at first achieved. The midship section of a modern welded cargo ship illustrated in Figure 4 shows considerable progress over such early designs. The saving in weight of hull material from the riveted ship in Figure 3 is obvious and largely due to the elimination of

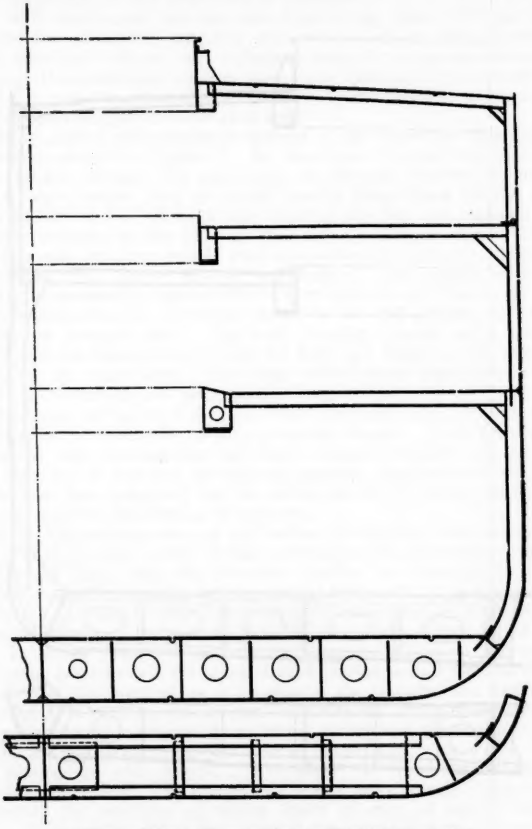


Fig. 4—Midship Section Modern Welded Cargo Ship

faying flanges, plate laps, etc. The frames and beams are inverted angles cut from channels. In this particular design the second and third deck beams; also the reverse bars on open floors, were serrated and cut from channels. The beam connections to frames are angles instead of ordinary plate knees. This midship section is fairly typical of the welded cargo ships being built today although there are many differences in detail in the ships now under construction which cannot be described within the scope of this paper.

Various types of hold frame margin connections in association with a flat tank top are shown in Figure 5. A shows the usual riveted plate bracket connected with tee bars to the tank top and with reverse bar and back bar directly underneath. B is a detail of a welded type of connection used in the vessel shown in Figure 4, where the hold frame is cut at and welded to the knuckled margin plate and reinforced by a flat bar gusset welded to the frame flange and to the floor plate and fitted continuously through the slotted margin plate. In detail C the hold frame is knuckled, the gap between the back of the frame and the shell being filled in by a welded plate. In detail D the cutting of the web of the frame near the frame flange facilitates the forming of the knuckle. The type shown in E is intended to

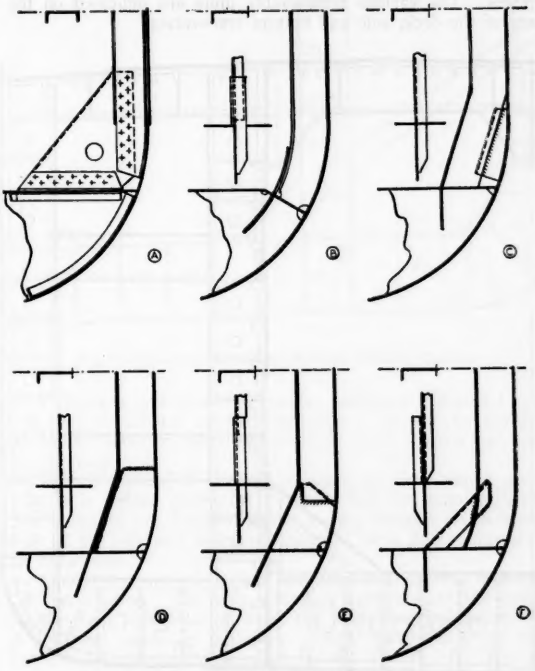


Fig. 5—Various Types of Hold Frame Margin Connections

eliminate bending of the main hold frames in the midship body; the bracket between the main frame and the tank top was cut from an 18-inch channel. In detail F the angle gusset is in some cases butted to the main frame and not lapped as shown in the sketch. It should be emphasized that these details are not intended to be directly comparable as far as size of hold frame, etc., is concerned. They do, however, serve to show the differences of opinion with regard to what constitutes an effective and economical welded hold frame connection. Such diversification is inevitable and even desirable during the present transition stage from riveted to welded construction.

Figure 6 is a midship section of a riveted tanker on the longitudinal system of framing, a modern twin bulkhead type, i.e., with two longitudinal bulkheads and three oil tanks abreast. The shell and deck longitudinals are channels and bulb angles. It is interesting to note the large number of angle clip attachments, in most cases double riveted incidental to riveted construction.

Figure 7 shows a midship section of a modern welded tanker. This looks like a simple structure compared with Figure 5 due to the absence of clip attachments, plate laps, etc. The longitudinals are of the inverted angle type, the smaller sizes being rolled angles and the larger sizes formed from flanged plates. The various preassembly units are indicated on the section by the laps of the deck, side and bottom transverses.

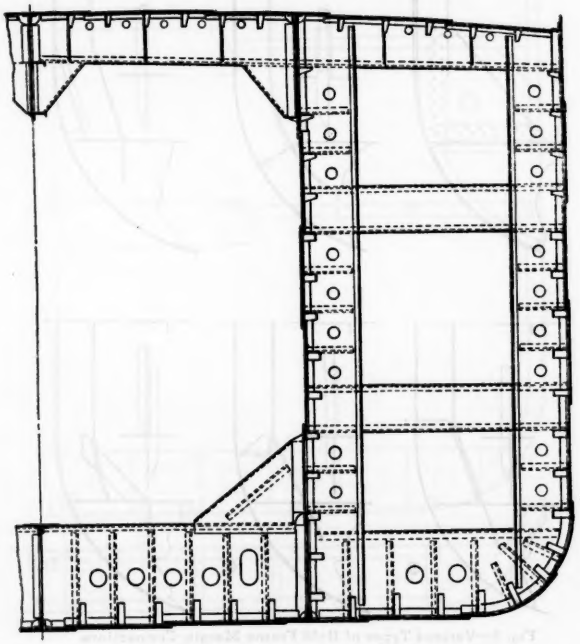


Fig. 6—Midship Section of Riveted Tanker

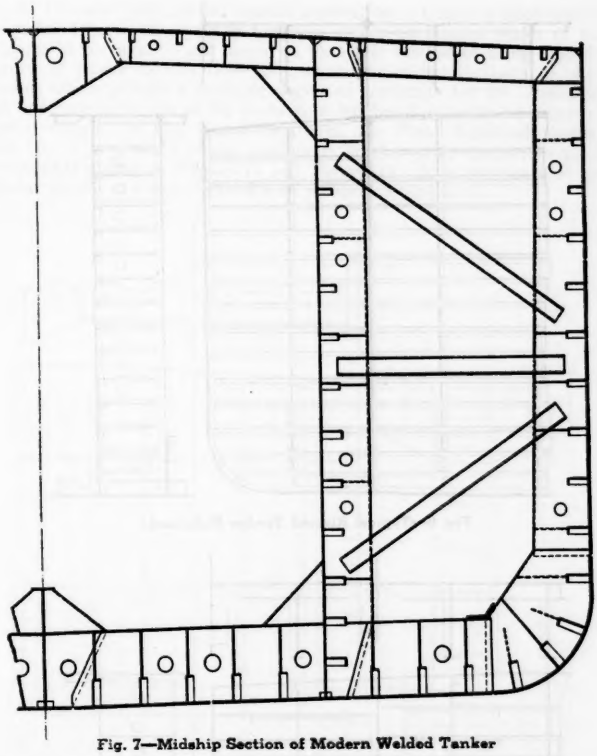


Fig. 7—Midship Section of Modern Welded Tanker

Figure 8 shows a typical riveted tanker bulkhead stiffened by large vertical webs and horizontal channel stiffeners. It will be noted that the bulkhead double boundary bars are fitted in short lengths and butt welded in lieu of joggling.

Figure 9 is a somewhat similar bulkhead to that shown on Figure 8 except that it is welded instead of riveted. The horizontal stiffeners at the top of the bulkhead are inverted rolled angles, flanged plates being used at the bottom of the bulkhead as rolled angles of these dimensions are not commercially obtainable.

Figure 10 shows a welded tanker bulkhead built on the Bethlehem-Frear system of construction. The main stiffening members are the center vertical web and the two horizontal girders, the vertical fluted plates taking the place of the usual secondary stiffeners. These fluted plates are pressed into shape hot and joined by continuous lap welds.

Figure 11 shows another type of welded bulkhead for a tanker where the bulkhead plates were dished to the form shown, at the plant of the Lukens Steel Company.

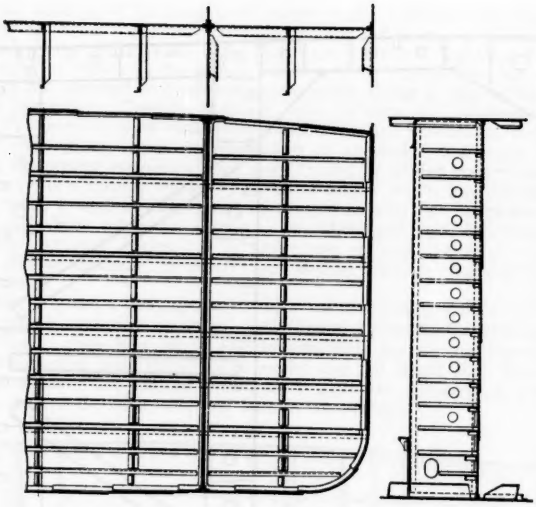


Fig. 8—Typical Riveted Tanker Bulkhead

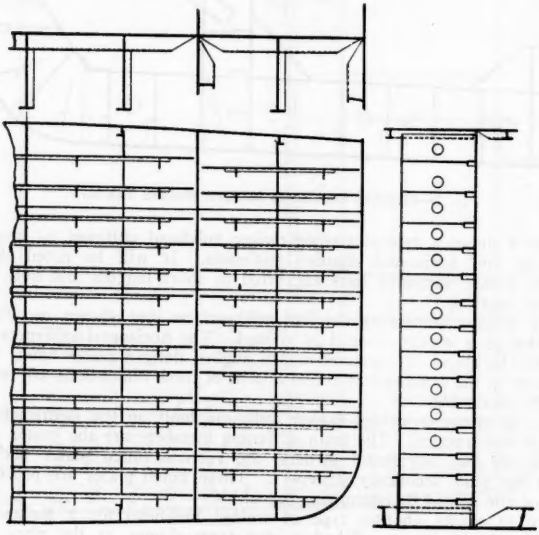


Fig. 9—Welded Tanker Bulkhead

Figure 12 shows still another special application, a tanker welded bulkhead built on the Isherwood corrugated system, where the shaped plates of varying depths of corrugation are butted at the edges instead of being lapped.

Figure 13 shows various types of connections of longitudinals to oiltight bulkheads which provide a desirable degree of continuity for the longitudinals which are necessarily cut at the transverse bulkheads in order to provide for proper drainage. A and B are details of the Frear bulkhead shown in Figure 10. C is a detail of the continuous bracket plate connection used in the bulkheads shown in Figure 11 and Figure 12. It is obvious that these particular details are only applicable to welded construction.

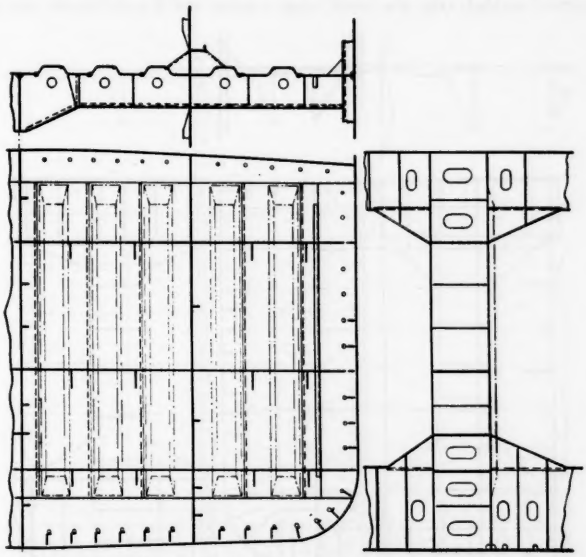


Fig. 10—Welded Tanker Bulkhead—Frear System of Construction

In the year 1934 I presented a paper to the Society of Naval Architects and Marine Engineers entitled "Some Examples of Arc Welded Ship Construction," outlining the development of ship welding up to that time. It is always interesting to go back and see what one has said on some specific subject and a review of that particular paper emphasizes the tremendous development that has taken place in the application of welding to ship construction in this country during the past six years. It is only some 12 years ago since the plans were approved for the first all-welded piece of floating equipment to be built under American Bureau classification, a small propelled oil barge *Supertest* ex *Pioneer* 102 × 20 × 8 feet which by the way was welded throughout with bare wire. The largest all-welded ship described in the paper was the tanker *Poughkeepsie Socony* 252 × 40 × 14 feet completed in 1934 and designed for Great Lakes, Canal & Short Coastwise Service.

Tanker owners were the first to grasp the significance of welded construction, the advantages being readily apparent in the case of oil-carrying vessels such as saving the hull material of the order of 15 to 20 per cent with consequent increased deadweight, superior oiltightness, easier cleaning of tanks and cheaper repairs. The Atlantic Refining Company on the basis of their satisfactory experience in service of their small all-welded tankers *White Flash* and *Franklin* built by the Sun Shipbuilding Company in 1931 and 1934, respectively, undoubtedly gave a boost to ship welding when they ordered the large tanker *J. W. Van Dyke* from the same builders. In this tanker, also the ships *Pennsylvania Sun* and *Robert H. Colley* which were delivered in 1938, all the middle bodies comprising the cargo oil tanks were completely welded, only the ends being riveted and I understand that these

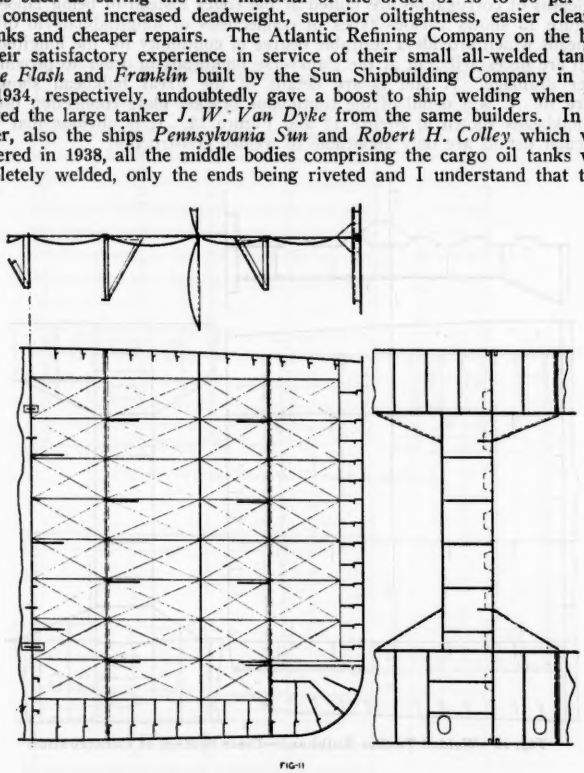


FIG-11

Fig. 11—Welded Bulkhead with Dished Plates

vessels have given every satisfaction in service. The later tankers of the same dimensions and type, the *E. J. Henry* and *Robert C. Tuttle,* were completely welded as will also be 13 similar tankers now under contract for various owners at the plant of the Sun Shipbuilding Company. This company was the first shipyard to apply the Unionmelt Process of automatic welding which is now being used quite extensively and so successfully in ship welding in this country.

In the last few years the use of ship welding has accelerated to such an extent that we are rapidly approaching that stage of development where welding will become the normal method of joining together the various parts of the ship's structure. This is borne out by the fact that all of the 149 ships under 300 feet long, building or contracted for to American Bureau

class on September 1, 1940, and comprising barges, ferryboats, towboats, small tankers, etc., are to be completely welded. There are also 177 ships over 300 feet long now building to Bureau class of which no fewer than 41 will be all-welded including such large ships as the 13 521-feet tankers building by the Sun Shipbuilding Company, the 15 465-feet C-3 type Maritime Commission cargo vessels under contract at the Pascagoula plant of the Ingalls Shipbuilding Corporation, the two 390-feet Maritime Commission C-1 type cargo ships building by the Pennsylvania Shipbuilding Company at Beaumont, Texas, and the 9 vessels for the Maritime Commission building by the Western Pipe and Steel Company at San Francisco. Of the 136 remaining large vessels, 135 are part welded including practically the whole internal structure and in some cases only the shell and strength

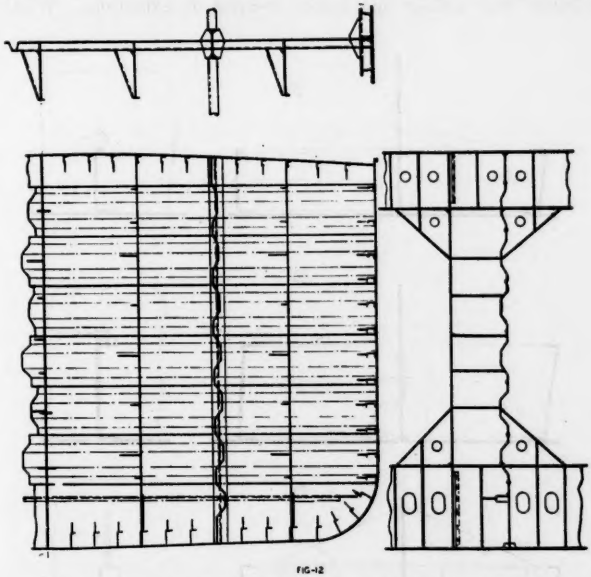


Fig. 12—Welded Tanker Bulkhead—Isherwood Corrugated System

deck longitudinal seams are riveted. Only one vessel, a large carferry building on the Great Lakes, can be properly termed a riveted vessel although even in this particular case a certain amount of welding is being done. These are remarkable figures which reflect the increasing confidence in the structural efficiency of welded ships and the realization on the part of our shipowners of the many advantages to be gained by the new method of construction.

In order to amplify the foregoing résumé a table has been prepared to show the comparative application of riveting and welding in the principal parts of the larger merchant ships now under construction in U. S. shipyards. A study of the information given in the table only goes to show that in most cases part riveted rather than part welded would more aptly describe

those ships that are not completely welded. For example, in the case of the ships building by the Seattle-Tacoma S. B. Corporation only the frames to the side shell are riveted. It will be noted also that the particular shipyards which are building completely welded vessels exclusively are, as would be expected, our new shipyards. The older yards still have their equipment for riveting, also a staff of trained riveters whom they naturally desire to keep in employment if at all possible. Owners' representatives have also something to say in the question of whether to rivet or weld, although in the case of the vessels ordered by the Maritime Commission the builders were given a free hand in the matter.

When welding was first introduced in our shipyards some 25 years ago bare wire electrodes were used exclusively and the work was usually left to some handy man without any special training or experience. While the

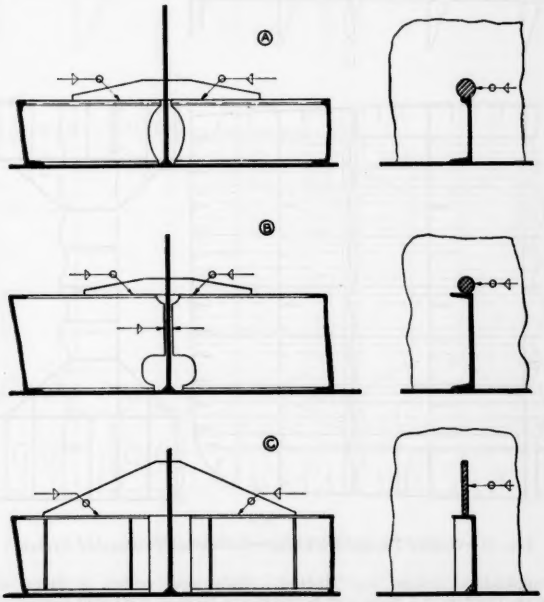


Fig. 13—Connections of Longitudinals to Oiltight Bulkheads

use of welding in those early days was confined to repairs and to comparatively unimportant structural details the results did not always inspire confidence so that considerable prejudice and antipathy on the part of shipyard executives and owners' superintendents had to be overcome before welding came into its own. Bare wire versus covered elctrodes is no longer an issue as bare wire welding is as dead as a "dodo" so far as modern shipyard practice is concerned. The work of the Navy Department in setting up standards for ship welding, testing of welders and welding procedures for

COMPARATIVE APPLICATION OF RIVETING AND WELDING IN LARGE MERCHANT VESSELS
UNDER CONSTRUCTION OR CONTRACTED FOR, ON SEPTEMBER 1 1940,
TO A. B. S. CLASS, IN UNITED STATES SHIPYARDS.

BUILDER	LENGTH	TYPE	NUMBER OF VESSELS	SHELL		WEATHER DECK			LOWER DECKS			BULKHEADS				FRMS		FLOORS		T.T. PLTG.	
				SEAMS	BUTTS	SEAMS	BUTTS	BEAMS-LONGITUDINALS	SEAMS	BUTTS	BEAMS-LONGITUDINALS	SEAMS	BUTTS	STIFFENERS	BOUNDARY	TO SHELL BOTTOM	TO SIDE SHELL	TO SHELL	TO TANKTOP	SEAMS	BUTTS
BATH IRON WORKS CORP.	400	CARGO - C	4	R	W	R	W	W	W	W	W	W	W	W	R	W	R	W	W	W	W
BETH. STEEL CO. QUINCY, MASS.	450	C	3	R	W	R	R	R	R	W	R	R	W	W	R	R	R	R	R	R	W
DO.	487	TANKER-T	3	R/W	W	R	W	R	W	W	W	W	W	W	W	W	W	W	W	W	W
DO.	450	T	4	R/W	W	R	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
DO.	505	T	2	R/W	W	R	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
BETH. STEEL CO. SPARROWS PT., MD.	525	T	1	R	W	R	W	R	W	W	W	W	W	W	W	W	W	W	W	W	W
DO.	465	C	4	R	R	W	W	R	W	W	W	W	W	W	R	R	R	R	R	R	R
DO.	450	C	6	R	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
DO.	395	C	5	R	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
DO.	487	T	8	R/W	W	R	W	R	W	W	W	W	W	W	W	W	W	W	W	W	W
DO.	442	T	5	R	R	R	R	R	R	W	W	W	W	W	W	W	R	W	W	W	W
BETH. STEEL CO. SAN FRAN., CAL.	395	C	5	R	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
BETH. STEEL CO. S.I., N.Y.	395	C	5	R	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W

DO	[illegible]	T	8	R/W	W	R	W	R	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
DO	442	T	5	R	R	R	R	R	R	W	W	W	W	W	W	W	R	W	W	W	W
BETH. STEEL CO. SAN FRAN., CAL.	395	C	5	R	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
BETH. STEEL CO. S.I., N.Y.	395	C	5	R	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
CARGILL INC.	400	C	1	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
CONSOLIDATED STEEL CORP. LTD.	395	C	4	R	W	W	W	W	W	W	W	W	W	W	W	R	R	R	W	W	W
FEDERAL S.B.&D.D. CO.	465	C	4	R	R/W	W	W	W	W	W	W	W	W	W	W	W	R	W	W	W	W
DO	395	C	5	R	W	W	W	W	W	W	W	W	W	W	W	W	R	W	W	W	W
DO	435	C	8	R	W	W	W	W	W	W	W	W	W	W	W	W	R	W	W	W	W
DO	440	T	1	R	R	R	R	R	R	W	R	W	W	W	W	R	R	W	W	W	W
DO	505	T	4	R	W	R	W	R	W	W	W	W	W	W	W	W	R	W	W	W	W
INGALLS S.B. CORP.	465	C	8	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
DO	465	C	7	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
MANITOWOC S.B. CO.	386	C	1	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
MOORE D.D. CO.	465	C	3	R	R	W	W	W	W	W	W	W	W	W	W	W	R	W	W	W	W
NEWPORT NEWS S.B. & D.D. CO.	525	T	1	R	W	R	W	R	R	W	W	W	W	W	W	W	W	W	W	W	W
DO	465	C	7	R	W	R	W	R	R	W	R	W	W	W	W	R	R	R	W	R	W
DO	465	C	2	R	W	R	W	R	R	W	R	W	W	W	W	R	R	R	W	R	W
DO	435	C	1	R	W	R	W	W	R	W	W	W	W	W	W	R	R	R	W	R	W
PENNSYLVANIA SHIPYARDS INC.	390	C	2	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
PUSEY & JONES CO.	390	C	2	R	W	W	W	W	W	W	W	W	W	W	W	W	R	W	W	W	W
SEATTLE TACOMA S.B. CORP.	395	C	5	W	W	W	W	W	W	W	W	W	W	W	W	W	R	W	W	W	W
DO	465	C	4	W	W	W	W	W	W	W	W	W	W	W	W	W	R	W	W	W	W
SUN S.B.&D.D.CO.	465	C	4	R	W	W	W	W	W	W	W	W	W	W	W	W	R	W	W	W	W
DO	375	T	1	R	W	R	W	R	W	W	R	W	W	W	W	W	R	W	W	W	W
DO	521	T	13	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
DO	485	T	4	R	W	W	W	W	W	W	W	W	W	W	W	W	R	W	W	W	W
DO	450	C	8	R	W	W	W	W	W	W	W	W	W	W	W	W	R	W	W	W	W
DO	500	T	5	R	W	R	W	R	W	W	W	W	W	W	W	W	R	W	W	W	W
TAMPA S.B.& ENG. CO.	435	C	7	R	W	R	W	R	W	W	W	W	W	W	W	R	R	R	R	R	W
WELDING SHIPYARDS INC.	500	T	1	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
WESTERN PIPE & STEEL CO.	395	C	5	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
DO	465	C	4	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W

R/W - INDICATES RIVETED SIDE & WELDED BOTTOM

navy ships with a view to the utmost possible saving in weight, an essential feature of navy design, and the early encouragement and approval given by the American Bureau of Shipping for welding important structural members in merchant ships undoubtedly served to encourage the development of welding in our shipyards. The activities of the American Welding Society, its publications and research work, have been stimulating and entirely helpful in assuring builders and owners that welding can be made safe and sound.

Advantages of welded construction to the shipowner such as increased deadweight capacity and lower maintenance costs are becoming generally recognized but what about initial construction costs? So far as barges are concerned especially those of rectangular section and rake ends of which so many are built on our rivers, usually in lots of 10 to 30, it can be stated quite definitely that there is a decided saving in initial cost as compared with riveted barges of the same type and our river yards are now building welded barges exclusively. The barge building business is highly competitive and it is significant that such important river yards as the Dravo Corporation and the Leetsdale plant of the Bethlehem Steel Company are now laid out for welding and quantity production, the Dravo plant, for example, being equipped for a line assembly of barges, the bulk of the welding being done under cover. At the Leetsdale plant the automatic carbon arc process is used quite extensively and a considerable use is made of jigs and fixtures to the exclusion of mold loft work.

The comparative costs of riveting and welding so far as the large oceangoing ships are concerned are somewhat more elusive, depending on the facilities of the particular yard, such as available storage and assembly spaces, crane capacities, welding equipment, method and sequence of preparing sub-assemblies, etc. Costs can be cut by careful planning in the initial stages of the design to ensure that only the minimum amount of welding is specified and so arranged that the maximum amount of welding can be done in the down-hand position. The advantage of using large plates to cut down the number of joints is, of course, obvious always with due regard to the extras charged for plates over certain sizes and to weight tolerances. Mr. E. C. Rechtin of the Bethlehem Steel Corporation in an address to the New York Section of the American Welding Society, published in the April issue of the Journal, discussing the economics of ship welding had no hesitation in affirming "that properly designed welded ships constructed in a properly laid-out yard are not more expensive to build than riveted ships" and went on to say "that the cost of a riveted ship expressed in man hours per ton was not likely to get any less as time goes on while the whole trend of development in ship welding is in the direction of reducing costs." It seems safe to say that so far as this country is concerned cost is no longer an important factor in the choice between riveting and welding.

The welded ships built in our shipyards have so far been free from serious structural troubles in service but it is entirely too early to jump to the conclusion that troubles will be non-existent as it will take years of operation under the varied service conditions before we can claim definite superiority for the welded ship structure. Welding is now being commonly used in the construction of the larger oceangoing type vessels where the service stresses are relatively much higher than in the smaller ships and for these important and complicated structures the best welding is none too good if trouble is to be avoided throughout the useful service life of the ship which is usually assumed to be around 20 to 25 years. Oceangoing ship structures especially tankers are subject to considerable corrosion depending on the degree of maintenance and since welding can make no difference in this respect the desirable margins provided for wear and tear in riveted ships must necessarily be retained.

The ideal of a perfectly homogeneous structure where the base metal and the weld metal have exactly the same characteristics and proprties is not obtainable. A fusion weld is essentially a casting having comparatively low ductility and the fatigue strength of deposited weld metal is definitely lower than that of mild steel. Welds should, as far as practicable, be free from porosity, inclusions and incipient cracks all of which act as stress raisers. Lack of penetration and undercutting are obvious defects which may impair the efficiency of the joint to the extent of becoming dangerous and the aim should be to produce welded joints with the maximum degree of reliability. Fortunately, we have in ordinary commercial mild steel a material which is inherently suitable for welding. Any steel can be satisfactorily welded using special welding technique in association with preheating or so-called stress relieving but what shipbuilders require is a steel which can be reliably welded with the exercise of ordinary precautions and reasonable care to the exclusion of any heat treatment. Existing standard specifications for structural steels were drawn up for use in riveted structures without regard to weldability as a primary characteristic and it may be that some revision could properly be made in such specifications with a view to obtaining a higher degree of weldability without any sacrifice of desirable physical properties and, of course, without any increase in cost. Some shipbuilders are specifying a maximum carbon limit in their steel orders, a desirable condition which is easily met but which will tend to the production of hull steel with the ultimate tensile strength well within the present allowable upper limit of the allowable tensile range of 60,000 pounds to 72,000 pounds per square inch.

Efficient design, suitable materials and sound welds will preclude the possibility of major structural failures in our large welded ships. It should also be emphasized that adequate supervision of welders and welding equipment, and close and intelligent inspection of the job are essential. Unfinished work is not so readily apparent as in riveted construction. That failures of welded structures are possible even where actual working loads are easily determinable is evidenced by the classic case of the welded bridge at Hasselt, Belgium, which collapsed after a short period of service for no apparent reason. The material of the bridge was "Thomas" steel, a basic Bessemer steel which is in common commercial use in Belgium and France, this particular process being dictated by the nature of the high phosphorus ore readily available. Due to the brittle nature of the fractures the failure was by some experts attributed to the general unsuitability of this material for welding. Others, including the steel manufacturers, had no hesitation in blaming the welding and naturally enough the design has also come under some criticism. Several samples taken from the ruins were made available to a Committee of the Institute of Welding and from their published report it would appear that some at least of the welded joints were quite unsatisfactory. Apparently the design, material and welding are all under suspicion and certainly inferior design, unsuitable material and poor welding make up a dangerous combination which need not exist throughout the whole job to become absolutely fatal to the structure.

The present trend of arc welding in our shipyards is toward the use of larger electrodes and heavier currents, continuous welding rather than intermittent and plain unstrapped butt joints rather than overlaps. In some applications the plate edges are unprepared. The tendency today is also to lay more stress on testing and approving processes and toward a simplification of tests for the so-called qualification of the welding operator which is all to the good. Our shipyards are continually experimenting with various types of automatic equipment and improved applications of the various processes may be confidently anticipated.

The importance of the research activities of the American Welding Society in the interests of sound and economical design of important structures such as welded ships cannot be overemphasized. Considerable research work of special interest to shipbuilders is being carried out in Great Britain involving full-scale experiments on both welded and riveted specimens of plate and shape combinations, necessitating the use of special testing equipment which allows the application of loads up to 180 tons. This investigation is being financed by the shipbuilding interests jointly with the Institute of Welding. We in this country cannot afford to lag behind in research work of this kind which has a definite practical value. The activities of our own Welding Research Committee are limited only by the amount of funds placed at its disposal and I hope that our shipbuilders will see their way to contribute generously to the work of the Committee which is of national importance.

If this paper has given those members of the Society, who are engaged in other engineering fields, a better idea of the extent of arc welding now being applied in ship construction in the United States the primary purpose, for its preparation will have been achieved.

REVIEW OF THE STRATEGIC METALS.

The following article is reprinted from the October, 1940, issue of Metals and Alloys published by the Reinhold Publishing Corporation, East Stroudsburg, Pa.

A strategic material is classed as one which is not available in the United States in sufficient quantity to meet the needs of a rearmament program—large quantities must be imported. Such materials may even be regarded as strategic even in peace times, the cutting off of a supply of any of them interfering decidedly with domestic manufacture and needs.

Of the many metals and their alloys which are considered as strategic in the military or preparedness sense, the following seven are prominent:

Manganese	Tungsten
Chromium	Antimony
Nickel	Tin
Mercury	

The importance of most or all of these materials is so definitely great that the present preparedness and defense program of the U. S. Government would fail if the supplies of at least some of them should be interfered with. We are dependent in large degree on importations.

To clarify the present general situation as to these seven metals, we present on the following pages a series of reviews, written whenever possible, by men of authority in those fields. It should be said that some difficulty has been experienced in obtaining these statements due to the relations of certain companies and men to the Defense Program. In one case it has been necessary for this office to supply a discussion on nickel.

The relation of these strategic metals to any military preparedness program, together with the authors of the reviews, are briefly summarized as follows:

Manganese: This metal is essential to all steel making operations—no steel of any kind can be made without manganese. We are dependent on importations for the major portion of our consumption. Thus far no sub-

stitutes, at least on any large scale, have been found. Martin Gentry, assistant to the president, Cuban-American Manganese Corp., New York, contributes this discussion.

Chromium: This element is essential in many of the important high grade steels used in military equipment of all types—armor plate, stainless and heat-resisting steels, aircraft steels, and others. The preparedness program would be seriously crippled without its availability. S. H. Dolbear, of Wright, Dolbear & Co., 17 Battery Place, N. Y., is the authority on this material.

Nickel: The place of nickel in a defense program is analogous to chromium.

Tungsten: The many complex machining operations involved in producing munitions and military equipment of all kinds is dependent to a large extent on the metal tungsten—in high-speed steels and some of the carbide tools. It enters into other important alloy steels. Molybdenum is a reliable substitute in some cases and there are other carbide cutting materials. Dr. Colin G. Fink, professor of Electrometallurgy, Columbia Univ., New York, is the contributor—Chairman, Tungsten Committee, U. S. Munitions Board.

Antimony: A large use of antimony is in storage batteries which are more than ever essential to any large scale mechanized military equipment program. And there are other uses. G. A. Roush, editor of "Mineral Industry," reviews this subject.

Tin: This metal is a large factor in the military use of bearings, solder and tin cans. Direct substitutes are lacking, though there are partial ones. Dr. C. L. Mantell, consulting chemical engineer, New York, author of "Tin," authoritatively writes this discussion.

Mercury: The principal military use of this metal is a fulminate as a detonator. It is also a factor in anti-fouling paint for naval use. C. S. Wehrly, of the Merchants Chemical Co., New York, is the contributor.

MANGANESE.

By M. B. GENTRY.

The present situation of the United States in relation to manganese is marked by important steps that are being taken toward decreasing the nation's dependence upon distant foreign sources for its future supplies of this highly essential strategic material.

A large new plant is being built in Montana to concentrate domestic manganese ore, an existing plant in nearby Cuba is being expanded, and the government in its national defense program is moving to build up reserve stockpiles and to encourage the development of deposits within our continental boundaries.

Why Strategic: In reviewing the current manganese situation, it is advisable to consider first the broader aspects of the problem. Why is manganese a strategic material? How is it used? What countries are the major producers? What percentage of consumption is supplied by domestic production?

Manganese is ranked by many authorities as the United States' No. 1 strategic material. It is required as a deoxidizer and desulphurizer in the manufacture of every ton of steel, helping to produce a clean, sound metal. Approximately 14 pounds of manganese, it is estimated, are used in making one ton of steel.

The mineral is ordinarily consumed by the steel industry in the form of ferromanganese, an alloy containing approximately 80 per cent metallic manganese and the remainder mainly iron and carbon. Ferromanganese is produced from ore containing approximately 48 per cent manganese but preferably more. No substitute for ferromanganese in steel making has ever been successfully developed.

A manganese shortage in time of emergency would constitute, therefore, a dangerous bottleneck curtailing the output of steel—not only for armor plate, tanks, guns and other military weapons but also for the less direct requirements of national defense, the bridges, trucks, trains, buildings, machinery.

Imports: Against this background of manganese indispensability, the United States in the period since the World War has been forced to import more than nine-tenths of its consumption of ferrograde ore. The great bulk of this ore has come from such far-off sources as Russia, leading world producer, India and the African Gold Coast.

In 1937-1939, the United States imported for consumption an average of about 674,000 tons a year of its estimated average annual consumption of 705,000 tons.

Russia, which in some years has supplied as much as half of total imports, accounted for approximately 34 per cent of the imports in that 3-year period. The African Gold Coast sent 31, Cuba 18, India 9, and Brazil 7.5 per cent. Recently, South Africa has become a substantial supplier.

Shipments from nearly all these sources upon which the United States has relied in the past are extremely vulnerable to attack on the seas. Ore-loaded ships, for the most part, must cross long stretches of unprotected waters and, in the event we were engaged in war, would be menaced by submarines and bombing planes.

Russian manganese, shipped to America from the Black Sea port of Poti, must travel across 5,700 miles of the Mediterranean and the Atlantic to reach Baltimore. India is 10,000 miles from Baltimore, South Africa 7000, and the Gold Coast 4900.

Brazil, which during the 1914-18 World War developed into the United States' foremost source, is a somewhat safer source, but in wartime, shipments even from that South American country would be vulnerable to attack, as the record of that first World War proves. Present rail facilities for transporting ore from mine to coast, furthermore, are inadequate to handle the greatly-expanded production that would be necessary if the United States sought to replace other imports with Brazilian manganese.

In the last analysis, thus, the United States in an extreme emergency could count only on domestic production and such relatively safe nearby sources as Cuba, which at the nearest point is only 90 miles off the coast of Florida.

American and Cuban Supplies: During the first World War, Cuba supplied a portion of the United States' requirements and after the war, shipped small amounts, mainly from small high-grade deposits. In 1930, the Cuban-American Manganese Corp. undertook the development of low-grade Cuban ores. The company succeeded in developing a flotation process that, for the first time, could be applied to oxide manganese ores.

With the successful concentration there of ores of less than 20 per cent Mn to a grade of 50 per cent and better, Cuba during the past 3 years was one of the United States' three leading manganese suppliers. The Cuban-American company is now expanding its plant by approximately one-third to provide a capacity of 130,000 tons annually by January 1, 1941.

The United States has widely-scattered low grade deposits of a grade similar to those of Cuba, but domestic production, as has been noted, has supplied less than a tenth of the nation's ferrograde ore consumption since

1918. The grave emergency that year, when imports had dwindled and continued steel production was threatened, pushed domestic production to a peak of 311,000 tons, about 35 per cent of consumption.

During 1937-38-39, domestic production averaged about 31,000 tons annually, slightly under 5 per cent of the estimated consumption. This domestic picture is brightened considerably, however, by the recent announcement of the Anaconda Copper Mining Co. of plans to construct a 100,000-ton concentration plant at Butte, Mont. The plant is expected to be completed early in 1941.

The total capacity of both the finished Cuban-American and Anaconda plants does not, of course, come anywhere near equalling the total manganese requirements of the United States even during peace-time, but it does represent an important advance toward freeing the nation from dependence upon distant sources, an advance that had not been made prior to our entry into the first World War.

Stockpiles: Another step in manganese procurement that had not been taken before April 6, 1917, is the purchase by the U. S. Government of ore for stockpile purposes. This program was inaugurated late last year when the procurement division of the Treasury Department purchased the first 25,000 tons from Cuba. In all, the division has purchased 86,500 tons, and most of this is believed to have been delivered.

Subsequently, the Metals Reserve Co. was formed as a branch of the Reconstruction Finance Corp. to acquire manganese and tin. Contracts for 562,000 tons of manganese ore, including deliveries to be made over the next 3 years by Cuban-American and Anaconda, have been announced.

To the growing government stockpile must be added the reserves of private industry. On September 1, stocks in bonded warehouses totaled approximately 850,000 tons, despite unusually heavy withdrawals during August.

Electrolytic Manganese: Another factor to be taken into consideration in studying the manganese future is the electrolytic process which has been investigated by the U. S. Bureau of Mines. This process, which produces pure manganese (better than 99 per cent manganese) from low grade domestic ores, is still in the experimental stage, but a plant erected in Knoxville, Tenn., by the Electro-Manganese Corp. has been turning out about 1500 pounds a day.

Even with all these favorable developments, the United States' manganese problem is still a serious one. At a steel production rate of 90 per cent of capacity, a rate that was being exceeded in early September, the nation needs an estimated 850,000 tons of ferrograde ore a year. Existing domestic and Cuban production facilities and those under construction can supply but a part of that.

This production plus the reserves now on hand would give the nation a breathing spell of well over a year, however, in which to investigate and to develop the indicated avenues that lie ahead for meeting our manganese needs.

CHROMIUM.

By SAMUEL H. DOLBEAR.

Chromite is classed as a "strategic" mineral. Insofar as the United States is concerned, this is only correct in part.

The problem should be considered from the viewpoint of consumption by three industries, i.e., metallurgical, chemical, and refractory. In terms of ore, without regard to its chromium content, consumption is distributed about as follows:

Metallurgical	50 per cent
Chemical	20 per cent
Refractory	20 per cent
Miscellaneous	10 per cent

Insofar as ores which can be used in the manufacture of high grade ferrochromium are concerned, the strategic classification is correct. In the manufacture of chemicals, the controlling factor is one of economics which in normal times has led to the use chiefly of ores containing 44 to 46 per cent chromic oxide.

If technical practice had not advanced beyond that of 1918, ores for refractory purposes could, at a price, be produced in the United States in sufficient quantity to supply the trade.

Sources of Supply: Disregarding Russian output, published figures of which must be regarded with doubt, the most important sources of chromite in recent years have been Turkey, Southern Rhodesia, New Caledonia, South Africa, Yugoslavia, Cuba, Greece, and the Philippines.

Unfortunately figures of production do not differentiate between ores of various grades. Ores from certain of these countries are entirely unsuited to metallurgical use, and in some cases are too low grade to be used for economic production of chromium chemicals.

Metallurgical Ore: The steel industry in the United States is dependent on the use of 70 per cent grade ferrochromium. This requires ore containing at least 48 per cent chromic oxide, and a chrome-iron (metallic) ratio of not less than 3:1. Any change from this basis would have its effect on efficiency in the industry.

In Great Britain steel mills use ferrochromium of a chromium content of 60 to 65 per cent. Such alloy may be made from ore of a chrome-iron (metallic) ratio of 2.5:1.

Upon the exhaustion of stocks and inability to obtain fresh supplies of high grade ore, American steel mills may need to adopt the British standard. Chief sources of metallurgical ore are Turkey, Southern Rhodesia, New Caledonia, and India. Closing of the Mediterranean has cut off Turkish shipments at present.

Stocks of high grade ore in private hands are the largest in the history of the industry.

Specifications for metallurgical ore ordinarily call for a minimum of 48 per cent Cr_2O_3; iron (metallic) in an amount not to exceed one-third of the chromium (metallic); and silica not over 8 per cent. There is, however, in industry no rigid insistence on these specifications, which may vary somewhat from these figures. Government specifications heretofore have been limited to lump ore containing not over 10 per cent of fines which will pass a ½-inch mesh screen.

Lump ore is preferable in the manufacture of ferrochromium although concentrates and fines are also used.

Chemical Ores: Because it is more economical to do so, ore containing around 46 per cent Cr_2O_3 is ordinarily used in the manufacture of chemicals. While a limit is sometimes placed on the silica content, its presence in greater or less degree has little effect on the value of the ore. Domestic production of lower grades could conceivably supply the chemical industry, but would increase costs and reduce plant capacity. The "strategic" importance of chemical ores is, therefore, less than that of metallurgical ores. The chief source of chemical ore is Transvaal, with lesser amounts derived from Greece, Yugoslavia, the Philippines, New Caledonia, and some other countries.

Refractory Ores: In recent years the chief sources of these ores have been the Philippines and Cuba, with lesser amounts from Greece. The ore sought for the purpose is of such a chemical character as to produce, on heating, a chrome spinel. Philippine ore ordinarily contains:

Cr_2O_3 (minimum)	32 per cent
Fe (maximum)	11 per cent
Al_2O_3 (minimum)	25 per cent
SiO_2 (maximum)	5 per cent

Philippine reserves are estimated at 8,000,000 tons or more. Some Cuban ores are of similar composition; reserves, while substantial, are smaller than those of the Philippines. The presence of a higher chromium content does not usually affect the price.

Domestic Situation: In recent years mines within the United States have yielded only a few hundred tons annually. This has been chiefly used on the Pacific Coast. That domestic deposits are capable of expansion is shown by the history of operations in the 1916 to 1918 period. Prices during those years ranged as high as $1.00 to $1.25 per unit of 1 per cent Cr_2O_3 per short ton, f.o.b. mines. In 1918, the highest year of record, production exceeded 80,000 net tons. In California and Oregon many deposits near rail were exhausted and before the end of the war ore was being hauled 50 miles or more to shipping points. This would tend to decrease any further production rate. On the other hand, roads have been substantially extended during the intervening years, and the cost of truck operation substantially reduced.

Large low grade deposits have been opened up in Montana by the U. S. Bureau of Mines and the Geological Survey. Their chromium-iron ratio is around 1.6:1 which makes them unsuitable for metallurgical use by established methods. Research by the Bureau of Mines and by private agencies has been directed toward some plan to utilize this ore. Until such work has been carried further, it cannot safely be relied upon as a factor in national security.

Domestic deposits have yielded small tonnages of metallurgical ore in the past. Deposits in Alaska and Washington may yield larger amounts if they are developed and equipped but, so far as exploration has gone, do not indicate the presence of tonnages sufficient to supply the industry over any protracted period.

Some deposits in the Pacific Coast area are capable of yielding substantial tonnages of milling ore which can be beneficiated to yield high grade concentrates. These are probably more important potential sources of domestic supplies at present than low grade deposits of Montana and other places which do not respond to this treatment.

Summary: A large part of the chromite supply of the United States in recent years has come from deposits controlled by belligerents in the present war. In most cases long ocean hauls are involved. Supplies from Turkey and other Mediterranean sources have been decreased by military operation in that region. Other sources at present available may be threatened by further military developments.

Fortunately consumers' stocks in the United States are large. These have been supplemented to some extent by government stockpile purchases. Domestic mines cannot be considered as a readily available reserve in case of emergency. During the World War about 2 years was required to bring about substantial production.

In the case of extreme emergency industry can be adjusted to use ores of somewhat lower grade, but at increased cost of production and at decreased efficiency of operation.

NICKEL.

By EDWIN F. CONE.

Nickel has been classed as a strategic metal because, of the total American consumption, an insignificant amount is obtained in this country. The great bulk comes from Canada. That this metal is essential to any military program is self-evident.

As the war has progressed, nickel has become the least strategic of all the seven metals. This is due to the formation of the cooperative defense commission between Canada and the United States. This practically insures ample supplies for the duration of the war—unless the fortunes of the British Empire turn out more disastrously than is at all probable.

Importance: It is stated by one authority that "next to manganese, nickel is probably the most important metal in the development of a modern munitions program, and it is one of the few for which the country is practically entirely dependent on outside sources for its supply; there is no direct production of nickel in the United States, such small output as does exist (a few hundred tons a year) being a by-product of the electrolytic refining of copper."

Some regard chromium as equally important, or more so than nickel. "But without nickel and chromium," says another authority who classes tungsten with these two metals, "no battleships and no guns; without chromium and tungsten, no tools for the efficient fabrication of the countless parts and products that enter into modern armament."

Requirements: The consumption of nickel has expanded rapidly, due in part to new uses, developed largely by the International Nickel Co., through research. In 1913 the world output was 32,700 metric tons, increasing to 47,900 tons in 1918. After declining during the first war depression, it rose to 57,000 tons in 1929 and then, after further declines to 20,000 tons in 1932, it advanced to 113,000 tons in 1937. Consumption in this country in 1937 was 45,900 net tons. A reliable estimate of the quantity to be used in our preparedness program is not available.

Metallurgical Uses: The use of nickel enters into many ferrous and nonferrous products, most of which have military significance—alloy steels of many types; alloy cast steels; alloy cast irons, low, medium and high nickel; stainless steels of many kinds; non-magnetic and highly magnetic alloys; nickel silver, nickel bronzes, nickel brasses, copper-nickel alloys, nickel-aluminum alloys, malleable nickel, and so on.

Many of the military uses are identical with the ordinary industrial uses, but in addition to these, there are many strictly military uses.

In the Airplane: The importance of the airplane in war has been the one outstanding demonstration in the present European hostilities. Nickel, as well as aluminum, is essential. Quoting from a recent statement of President R. C. Stanley of the International Nickel Co.:

"Nickel steels and nickel alloys are widely used in airplane engines and this use exemplifies the diversified and exacting conditions for which these nickel-bearing metals are specified. Metallurgists have been able to provide materials which permit design changes and the use of improved fuels. Thus there has been developed the present highly efficient power unit which weighs approximately one pound per horsepower generated. Nickel steels with high fatigue resistance; nickel-aluminum alloys with increased tensile strength; nickel-chromium, resistant to the attack of exhaust gases; and other alloys of high nickel content, which stand up in the combustion chambers, have all contributed to this advance."

Substitutes: The problem of substitutes for any strategic metal is important—particularly manganese. Very few, if any, substitutes for nickel have been developed—they have not been needed due partly to the cheapness of the metal and the newness of the developments of its uses, and also because many of the uses of nickel are themselves substitutes for some other metal or alloy.

Germany has very limited supplies of nickel but in her armament program one substitute, particularly in stainless steels and other high nickel materials, has been manganese. Other substitutes used are not known.

Gilding metal, a special type of brass, instead of cupro-nickel for bullet jackets has been developed and other alloy steels might displace certain ones containing nickel.

Vital as nickel is to any military preparedness program, American industry is not likely to be in want of supplies nor in need of substitutes.

Tungsten.

By Colin G. Fink.

Tungsten has been a strategic metal in most countries ever since the introduction of tungsten steels and tungsten alloy tools.

Cutting Tools: Tungsten tools cut a hundred times faster than the old carbon steel tools and tungsten alloys are among the very toughest alloys used for instruments of offense as well as defense. Some essential properties of tungsten steels have been known for over 75 years. Self-hardening steel tools were invented by Robert Mushet between 1860 and 1870. But not until the Paris Exposition of 1900 did the modern era in tool steels begin. At that time, Frederick W. Taylor of Philadelphia first exhibited to the astonished gaze of incredulous machinists and metallurgists the spectacle of a tool cutting so fast and so deep that it delivered steel chips at a blue heat and in amazing quantities. A few years after this exhibition, Ellwood Haynes of Kokomo, Ind., introduced the cobalt-tungsten-chrome alloys, universally known today as the stellite high-speed tool alloys. A familiar stellite composition is 10 to 15 per cent W, 45 to 52 per cent Co, and 28 to 32 per cent Cr. A familiar Taylor steel composition is 18 per cent W, 4 per cent Cr, and 1 per cent V.

A few years ago, a third type of tungsten tool was introduced into industry, namely, tungsten carbide, usually cobalt-cemented and a product of powder metallurgy. This product is so hard that it has replaced the more expensive diamond in many applications. It is much harder than but not as tough as the Taylor or stellite tungsten alloys.

Occurrence: Tungsten occurs in nature predominantly as the tungstate of iron, mineralogically designated as ferberite; and the tungstate of calcium, scheelite. Less frequent is the occurrence as such of the tungstate of manganese, hübnerite. As a rule, hübnerite is associated with ferberite, the latter usually predominating in the so-called mineral "wolframite," the iron-manganese tungstate. The steel industry, which consumes over 90 per cent of the world's tungsten, prefers, as starting material, the 80 per cent W ferroalloy which must be practically free from deleterious impurities such as tin and arsenic, frequently found in tungsten ores. A big boom to the tungsten steel industry was the commercialization of the electric arc furnace. Tungsten is the highest melting of all metals (3360 degrees C.) and no fuel fired furnace can even approach this temperature. The melting point of pure 80 per cent ferrotungsten is 1640 degrees C.

The economically important tungsten ore localities are almost all situated in that great horseshoe-shaped chain of mountains bordering on the Pacific

Ocean and extending from the southern end of Malaysia north through Alaska and south through Canada and the United States, Mexico and South America (Andes). By far the largest producer of tungsten ore for the past 20 years has been China. Here the mineral is primarily wolframite and, although mining methods are relatively simple and crude, mining and transportation costs are the lowest of any. They are about 1/5 or 1/6 of the cost of mining tungsten in the United States.

Domestic Tungsten: Before the advent of China in the tungsten market, Burma and the United States contended for supremacy as the largest world producer. But with the receipt at San Francisco of Chinese wolframite concentrates, selling at a profit, at $1.50 and $2.00 per unit, the United States' tungsten industry virtually collapsed. And it required a protective tariff to partially resuscitate it. The U. S. Bureau of Mines in a recent report states that although "tungsten may be considered as a first priority strategic mineral, the position of the United States in this commodity is less severe than in the case of manganese, tin and chromium." For a number of years past, Nevada has been the largest tungsten producing state. The total United States production in 1939 amounted to 3900 metric tons of 60 per cent WO_3 concentrates as compared with a total consumption of 4750 metric tons and a world's tungsten production of 40,000 tons.

Just as cheap Chinese tungsten ore crippled temporarily the tungsten mining industry of the United States, so likewise was the reaction in other tungsten centers such as British India, Bolivia, Argentina, Spain and Portugal. (The Iberian peninsula is the only large, significant source of tungsten in Europe.) And while these countries were engaged in re-establishing the lost source of revenue, Germany at once encouraged further development of tungsten ore production in China, placed no restriction on its importation and for almost 10 years before this present world conflict started, piled up a vast tungsten ore pile in Germany far in excess of peacetime requirements and sufficient in quantity, as variously estimated, to supply her for six more war years to come, assuming no further importations.

Conclusion: Fortunately, our own tungsten resources comprise high-grade deposits usually free from deleterious impurities. And we feel certain that in an emergency the output of Nevada, Colorado, California and of other states can be increased many fold. Furthermore, tungsten's sister metal, molybdenum, can be substituted, in part at least, for tungsten in many important steels. And the United States has the largest molybdenum mine in the world, suppling over 85 per cent of the world's requirements.

Also, radical advancements have been made in tool design as to economies in tungsten (and cost) so that only the cutting edge, but not the shank, is made of tungsten steel or stellite.

And finally, the magnet alloy industry has been completely revolutionized during recent years. The permanent magnet steel carrying 4 per cent tungsten has been surpassed in quality and performance by the aluminum-nickel-cobalt alloys.

Nevertheless, when peace comes, it will be the tungsten alloys and their manifold applications that will be foremost in hastening the return of normal pursuits.

Antimony.

By G. A. Roush.

The commercial and strategic aspects of antimony have been radically altered during the past decade, largely through the establishment in 1931 of a domestic smelting plant using Mexican ores; a second factor of importance has been the growing demand for antimony compounds, especially the oxide, which is used as a pigment in fusible enamels and nitrocellulose lacquers.

Between these two factors a wholly new set-up has developed in the domestic situation. The antimony supply of the United States in 1929 was quite typical of that of the years preceding, and may well serve as an example of the status just preceding the establishment of the domestic smelting industry and the disturbances resulting from the prolonged industrial depression. During the past 25 years antimony consumption in the United States has absorbed from one-third to two-thirds and has averaged somewhat under one-half of the world output of new metal. Consumption in 1939 recovered from the 1938 recession, and while some of the final data are still lacking, those at hand indicate a general level about the same as in 1937, which may then be taken as representative of conditions in 1939, for comparison with 1929. This comparison brings out some interesting and pertinent points.

Domestic Smelting: The first smelter went into operation at Laredo, Texas, in 1931, using Mexican ores, and until 1938 this was the only plant in operation, aside from the long-established output of hard lead, some of which was from domestic and some from foreign ores. In 1938 a plant in Los Angeles began the treatment of antimony-mercury concentrates imported from Mexico; thus far this plant has operated only on a small scale, apparently about 200 tons of antimony a year. During 1940 another small plant is expected to go into production at Kellogg, Idaho, to treat antimony-bearing ores of the Coeur d'Alene region.

Sources of Supply: In 1929 the total apparent consumption of antimony in the United States was about 30,000 net tons. Following the heavy slump during the depression, with a low of 12,150 tons in 1932, consumption recovered to 26,200 tons in 1937, but the type of consumption and the sources of supply had been radically altered, as may be seen from the following table of comparison of antimony consumed in the United States.

	1929		*1937*	
	Short Tons	*Per cent*	*Short Tons*	*Per cent*
In crude imported	1,350	4.5	580	2.2
Metal imported	10,560	35.2	610	2.3
In alloys imported	300	1.0	410	1.6
Smelter output, metal	None		4,060	15.5
Smelter output, alloys	3,050	10.1	1,640	6.2
Secondary metal recovery	11,130	37.1	12,340	47.1
In compounds, domestic and imported	3,650	12.1	6,560	25.0
Total	30,040		26,200	

As a result of the establishment of domestic smelting, imports of metal have almost disappeared, and have been replaced by ore imports. This shift naturally made a corresponding shift in the sources of supply, as shown in the following tabulation of the percentage distribution of the total imports since 1915, dividing the time into three periods: The first, 1915-1930, previous to domestic smelting; the second, 1931-1935, covering the years required to put the smelting industry on an established basis; and the third, 1936-1939, covering subsequent years to date. The sources of antimony imports into the United States:

Imported from:	*1915-1930*	*1931-1935*	*1936-1939*
China	75.8	43.4	6.0
Mexico	8.1	48.0	62.2
South America	7.0	7.3	29.6
Others	9.1	1.3	0.2

Each of the four lines of this table has an important significance. First, Chinese imports were largely metal, and have now been reduced to insignificant proportions, the larger proportion of which is crude and oxide. Second, Mexico has practically entirely replaced China, by furnishing a more accessible ore supply for the domestic smelters. Third, South American ores, chiefly from Bolivia, during the first and second periods were of only minor importance, but during the third period have grown to a quite material proportion of the total; it is largely from these ores that the increased output of oxide has been made. And fourth, Mexican and South American ores have practically completely replaced imports from other sources, so that, except for the small amounts still received from China, the domestic antimony supply is centered in the Western hemisphere.

The growing demand for South American ores has resulted from the gradually increasing consumption of antimony oxide, which, as shown by the first tabulation, has more than doubled in consumption during the past decade, and still continues to expand. Curiously enough, this seems at the same time to have been accompanied by a decline in the demand for metal. In 1929, new metal and alloy content made available by imports and smelter output was 46.3 per cent of the total consumption, while secondary metal supplied 37.1 per cent, making a total of 83.4 per cent consumed in metals and alloys, against 12.1 per cent in compounds, chiefly oxide; in 1937 the proportions in new metal and alloys had dropped to 25.6 per cent, while secondary metal had increased to 47.1 per cent, a total of 72.7 per cent, against 25.0 per cent in compounds. The ratio of metal to compounds in 1929 was 6.9, but in 1937 this had dropped to 2.9.

Strategic Aspects: The establishment of domestic smelting has put the strategic position of antimony on a much more favorable basis than formerly existed. The consuming industry is supplied from sources not only far more accessible, but almost entirely in the Western hemisphere, a fact that under present conditions is of prime importance. Were the United States now largely dependent, as it was 10 years ago, on China as the main source of supply, the needs of the present rearmament program would at the best be seriously hampered; and considering the current situation in China and the attitude of Japan, supplies might well be cut off completely. The possibility of interruption of present supplies by outside agencies is much less likely, and transportation difficulties are materially reduced.

The existence of an established smelting industry in the United States also improves the strategic situation in other ways. The stocks of ore and metal normally maintained will be larger; it will be much easier and quicker to expand the capacity of an established smelting plant if and when emergency supplies are required than it would be to build a new one; and likewise, the expansion of an already operating ore supply will be simpler than the development of a new one.

Thus far the operation of domestic smelting has not had any effect on domestic ore production, no smelting of domestic ores having been carried on since the First World War, except for the usual run of hard lead. The new plant at Kellogg, Idaho, will be the first recent attempt to utilize domestic ores for the production of antimony metal, and therefore represents an important step in the program, but one in which possible future development is problematical, except under emergency demand and at prices scaled to fit the conditions involved.

Uses: In 1918 it was estimated that 11 per cent of the domestic antimony consumption went into ammunition. Future war demand for direct munitions work will be much less than this, as shrapnel is no longer used so extensively; but the same change that has outmoded shrapnel (the advent of motorized

equipment) has enormously increased the potential demand for antimony in storage batteries for use in the motorized equipment, and at the same time the civilian use of motor vehicles has been expanding rapidly. Where only 4.8 per cent of the antimony consumption went into storage batteries in 1918, this had grown to 28 per cent in 1928; no official consumption distribution figures are available since 1928, but in the meantime motor vehicle registrations have increased by about one-quarter, so that at the present time it is probable that more than one-third of the antimony consumption is going to storage batteries. As a matter of fact, taking into consideration the various other forms in which antimony enters into automobile construction (bearing metals, white alloys, rubber, pigments, etc.), it may be anticipated that the automotive industry now absorbs half or more of the total antimony consumption.

Mention has already been made of the increased use of the oxide, which in 1937 took one-fourth of the consumption, and this, combined with the size and importance of the figures referred to just above, emphasizes the desirability of having a new detailed survey made of the consumption of antimony, so that trends away from the former uses may be estimated more accurately. It is evident that radical changes have been made, but only a systematic and careful survey can give an accurate picture of present conditions and what we may expect in the future, and any estimate of possible future emergency demand is dependent on this information.

Tin.

By C. L. Mantell.

Tin is classed as a strategic material in that the United States, the major consumer, produces none, while the major producers consume little. From the advent of tin metallurgy to the present, about three quarters of all the metal has been obtained from ores originating in a relatively small geographic area which includes the Federated Malay States, the Netherlands Indies, Siam, Burma, Indo-China, and lower China. South America (mostly Bolivia) has contributed 12 per cent, all of Europe (including the British Isles) less than 11 per cent, Africa less than 11 per cent, and North America 0.02 per cent. All of the tin won in North America from the birth of the United States would satisfy normal American consumption for less than a week. The United States industry is more completely dependent on far-away sources of supply of tin than is the case with any other material. Insurance against interruption must take the form of adequate stock piles.

The statistical record of tin imports and moved production in its relation to the United States speaks for itself. (Table I).

Smelting: The United States uses nearly half of the world's production of tin, an amount which is greater than that of all the other leading industrial nations combined. It depends on smelters in Malaya, England, China, and the Netherland E. Indies; formerly supplies also came from a smelter in the Netherlands. Ore originating in Bolivia crosses the Atlantic Ocean to England so that later in the form of tin it may recross the Atlantic to New York.

For practical purposes, large smelters do not yet exist in the United States, although all the technical information, plant experience, and completed development work are available to enable us to treat "foul" Bolivian ores and produce satisfactory metal. During the first World War several successful smelters operated, but the last of them ceased in 1924. Twice in the past tin smelters were established in the United States. Political control

TABLE I*—SALIENT STATISTICS FOR TIN IN THE UNITED STATES, 1925-29 (AVERAGE) AND 1935-39.

	1925-29 (average)	1935	1936	1937	1938	1939
Production—						
From domestic mines ..... long tons..	24	44.5	101.0	168.4	95	34 [1]
From secondary sources ..... do.....	30,600	24,900	25,000	27,100	21,080	([2])
Imports for consumption (metal) ..... do.....	78,009	64,258	76,029	88,115	49,699	70,102
Exports (domestic and foreign) ..... do.....	1,740	2,292 [3]	386 [3]	313 [3]	205 [3]	1,997 [3]
Monthly price of Straits tin at New York:						
Highest ..... cents per pound..	70.67	52.29	51.85	62.71	46.23	63.50
Lowest ..... do.....	39.79	46.91	42.22	42.85	36.84	45.62
Average ..... do.....	56.64	50.39	46.42	54.24	42.26	50.20
World production ..... long tons..	163,000	135,300	179,000	211,200	159,900	181,000
Ratio United States imports to world production..per cent..	48	47	42	42	31	39

[1] Subject to revision.
[2] Data not available.
[3] Figures for 1935-39 cover foreign only; domestic not separately recorded.
* "Minerals Year Book," U. S. Bureau of Mines.

TABLE II*—WORLD SMELTER PRODUCTION OF TIN, 1925-29 (AVERAGE) AND 1935-39, BY COUNTRIES, IN LONG TONS.

[Compiled by R. B. Miller]

Country	1925-29 (average)	1935	1936	1937	1938	1939
Argentina	.....	591	591	734	1,093	(1)
Australia	2,952	2,837	2,717	2,907	3,229	(1)
Belgian Congo	.....	1,588	1,955	2,313	2,283	(1)
Belgium [2]	720	4,000	5,100	4,900	6,800	(1)
British Malaya [3]	88,855	60,479	84,591	95,372	63,746	81,536
China	7,080 [4]	9,700	10,400	11,100	11,200	(1)
Germany [5]	3,444	2,042	2,293	2,671	3,000	(1)
Italy	.....	241	286	75	271	(1)
Japan	606	2,036	1,841	1,850	1,900	(1)
Netherland E. India [4]	14,749	11,221	12,854	13,757	7,207	14,788
Netherlands [2]	1,000 [6]	15,600	20,900	26,600	25,561	15,024
Norway	(1)	454	233	241	254	(1)
Portugal	2 [7]	1	.....	.....	39	(1)
Thailand (Siam)	113 [8]	(9)	(9)	(9)	.....	(1)
United Kingdom [2]	45,800	29,100	34,200	33,800	36,200	(1)
	165,000	139,900	178,000	196,300	162,800	(1)

[1] Data not yet available.
[2] Estimated.
[3] Exports plus difference between carry-over at end and beginning of year.
[4] Exports.
[5] Includes production of some secondary tin.
[6] Estimated production in 1929.
[7] Average for 1926-27.
[8] Average for 1926-28.
[9] Less than 1 ton.
* "Minerals Year Book," U. S. Bureau of Mines.

in the shape of an export duty on concentrates caused the failure of the first, while commercial control due to more favorable economic conditions abroad put an end to the second.

Sources and Distribution: The world sources of tin are indicated in Table II. The industrial distribution of primary (or imported) tin and secondary (or "circulating") metal is indicated in the Table III, while the sources of the original metal are indicated in Table IV.

Uses: The major uses of tin are tin plate, solder, bearing metals, bronzes, type metals, collapsible tubes, foil and tin chemicals.

For many of these uses substitutes find employment in times of stress. In the case of foods, other than for esthetic reasons, a considerable number of them may be packed in black plate. In recent years steel electroplated with silver has been suggested for containers, copper-plated steel for oil cans, aluminum (particularly in connection with fish), stainless irons, as well as base metals carrying organic coatings. Enamelware, aluminum, and nickel have largely replaced tin plate in cooking utensils while copper, zinc, and lead-coated products have supplanted tin and terne plate for roofing. Tin foil has suffered from competition of aluminum, cellophane, transparent papers, and lead, while in collapsible tubes aluminum and lead for nonfood purposes have made inroads. Development work on zinc collapsible tubes has been carried to the stage of commercial usage during emergencies.

TABLE III*—CONSUMPTION OF TIN IN THE UNITED STATES, 1936-38, BY FINISHED PRODUCTS (TIN CONTENT), IN LONG TONS.

	1936			1937			1938		
	Primary	Secondary	Total	Primary	Secondary	Total	Primary	Secondary	Total
Tin plate	33,750	.....	33,750	39,221[1]	.....	39,221	23,545[1]	.....	23,545
Terne plate	369	943	1,312	382	1,015	1,397	264	743	1,007
Solder	12,068	6,682	18,750	12,026	7,832	19,858	7,590	5,208	12,798
Babbitt	5,070	1,609	6,679	4,501	2,272	6,773	2,893	1,264	4,157
Bronze	3,559	2,631	6,190	3,712	2,784	6,496	2,334	1,598	3,932
Collapsible tubes	3,556	.....	3,556	3,571	(2)	3,571	3,427	.....	3,427
Tinning	2,377	13	2,390	2,585	67	2,652	1,738	35	1,773
Foil	1,645	43	1,688	1,456	4	1,460	879	(2)	879
Chemicals (other than tin oxide)	209	1,346	1,555	171	1,331	1,502	166	910	1,076
Pipe and tubing[3]	1,401	82	1,483	1,278	18	1,296	948	(2)	948
Tin oxide	969	361	1,330	793	411	1,204	547	444	991
Type metal	253	919	1,172	221	1,140	1,361	134	978	1,112
Galvanizing	1,016	.....	1,016	997	(2)	997	792	.....	792
Bar tin	656	84	740	652	174	826	456	213	669
Miscellaneous alloys	418	62	480	482	24	506	238	19	257
White metal	358	9	367	374	33	407	390	44	434
Miscellaneous	558	34	592	506	97	603	371	107	478
	68,232	14,818	83,050	72,928	17,202	90,130	46,712	11,563	58,275

[1] Includes small quantity of pig tin derived from detinning operations; Bureau of Mines not permitted to publish separate figures.
[2] Small quantity included under "Miscellaneous."
[3] In 1936 pure tin tubing required 1,476 tons and tin-lined tubing 7 tons; in 1937, 1,286 and 10 tons, respectively; not reported separately after 1937.
* "Minerals Year Book," U. S. Bureau of Mines.

Effective recovery of the tin from tin plate clippings is made, but the tin content in the average can is lost in the garbage dump. Severe dislocation of natural silk by rayon has markedly affected the consumption of tin chemicals for weighting so that by-product metal, oxides, and plating chemicals are produced instead. Tin oxide as an opacifying agent in glass and vitreous enamels meets effective competition from oxides of antimony, titanium, and zirconium.

Solders: In solders, cadmium alloys have been proposed and found some use, while bearing metals of the babbitt type are being replaced by other alloys or by mechanisms such as ball and roller bearings. Copper-lead calcium-lead, cadmium-copper-lead, cadmium-silver alloys are all employed as effective and prospective savers of tin. In the bronzes no satisfactory substitute for tin exists, but other alloys of copper, particularly with aluminum, silicon, or manganese, can replace bronze.

Military uses of tin in general are adaptations of the ordinary industrial applications, but in times of conflict between nations the consumption of tin, particularly as tin plate, tin cans, solder, and tin alloys, markedly increases.

TABLE IV.*

Country	1938		1939	
	Long tons	Value	Long tons	Value
Argentina	482	$437,762	251	$256,516
Australia	130	126,914	250	256,498
Belgian Congo	75	77,376	100	123,220
Belgium	395	394,518	1,320	1,429,471
Bolivia	25	22,355	.....	.....
British Malaya.....	36,673	32,952,813	46,785	47,139,136
Canada	11	8,908	3	2,358
China	2,084	1,807,756	3,259	3,015,954
Cuba	1	481	.....	.....
Germany	20	17,109	.....	.....
Hong Kong	1,204	1,034,384	1,062	999,133
Indochina, French..	.....	.....	25	24,877
Netherland India...	3,096	2,716,274	5,316	5,442,528
Netherlands	2,216	2,062,990	1,008	1,018,181
Panama (Canal Zone)	.....	.....	(2)	91
Portugal	.....	.....	25	27,227
Sweden	(2)	15	.....	.....
United Kingdom....	3,287	3,200,669	10,698	10,855,574
	49,699	44,860,324	70,102	70,590,764

[1] Bar, pigs, blocks, grain, granulated, or scrap, and alloys, chief value tin, n. s. p. f.

[2] Less than 1 ton.

* "Minerals Year Book," U. S. Bureau of Mines.

The status of tin in a preparedness program would be improved by the appearance of commercial smelters in the country, backed by adequate stock piles to cover normal requirements of two or more years. With tin metal normally available, work on substitutes is largely stimulated by some competitive material which seeks a place in the sun. These substances, however, act more as a brake on the tin price than as a mechanism of elimination of tin. In times of stress, however, they may become important aids.

American Smelters: Two American smelters, operating on Bolivian ores are now in operation, a third is contemplated. Output is not large enough to have any appreciable effect in reduction of imports.

In a commercial sense the United States or its possessions has never produced any tin ore, although specimen deposits are known to exist in a large number of locations. The tin content in a pile of old cans in a refuse heap would show a higher tin value than most of our available ore sources. Increases in supply resulting from increased prices of tin would come from secondary sources rather than mining. Until exports were restricted, tin plate scrap in large quantities left the United States. As a conservation measure, the same procedure should be adopted for drosses, slags, and tin-bearing materials so that the tin recovery from these secondary sources may be carried on in the United States to augment our supply.

Mercury.

By C. S. Wehrly.

The cycle theorists adapt their formula to many uses. Possibly present phraseology is but a rewording of old beliefs. Atomic change was expressed in terms of a common metal of which mercury was an element. Recent trials proved the inadequacy of present methods to transmute mercury to gold, the value of each is definite.

The low tenor of mercury ore treated in this country is paradoxically of definite benefit. For over 20 years the average metallic content has been but slightly over 0.60 per cent, while for the past 10 years this has declined to under 0.40 per cent. Even with the present duty of over $19.00 per flask, prices in this country are definitely dependent upon prices quoted by Spain and Italy. Thus during periods of low prices our production declines, the converse being equally true. Thus we have a balance or brake upon the hundred odd mines now reporting production which acts to hold our ore in the ground during poor periods and permits fullest operation during peak times. This may be deplored by the producers themselves but reacts to the Nation's benefit.

Output and Prices: Mercury was classified as a strategic metal by the Government and placed upon the export license list. With the jump in prices from slightly over $80.00 in the summer of 1939 to over $200.00 within one year, production, which always lags from six to twelve months, rose from about 1500 flasks per month to 2200 as reported for February, 1940—2500 for March—2700 for April and 3100 for May.

With a present normal consumption need of from 26,000 to 30,000 flasks per annum this country almost from its initial recorded production in 1850 of nearly 8000 flasks, had up to 1921 been able to export certain quantities. From that year until the present we have been forced to import to make up a deficiency. We are at present freed from the necessity of importation but controlled by conditions outside of this country.

These supplies have come from the three other nations that commercially produce mercury—Spain, Italy and Mexico. While the metal has been found and refined in China, Russia, Germany, Turkey, Africa, Australia, New Zealand, Chile, Peru and other places, it is only these three nations who have produced sufficient quantities to have a marketable surplus. With Mexico's output of from 6000 to 10,000 flasks, Spain and Italy have supplied the world's needs, normally over 100,000 flasks. Top production has shifted between Spain and Italy but with the recent (1928) agreement, a common selling arrangement eliminated competition between them. The dominance of these two countries rests in vast reserves and rich ore—Spain over 7 per cent and Italy from ¾ to 1½ per cent.

With this power, price fluctuation was under control and limited merely by judgment as to consumer resistance and competitive production. Thus

during the years 1928, 1929 and 1930 prices in this country were in excess of $115.00 per flask and production rose from 11,000 flasks in 1927 to over 21,000 flasks for that period. Estimated reserves in the United States excluding ore testing lower than 0.1 per cent (a possible development) are placed at over 150,000 flasks. With widespread occurrence, possible undiscovered ore bodies and economic barriers upon production, this country does not need to fear a shortage in times of stress.

Uses and Substitutes: The value of mercury rests in the lack of substitutes and its widespread application. Its uses are so varied that each of us daily is affected by its presence. Generally the fields are divided into chemical, electrical and mechanical uses and adaptations. The first is today the largest; using over 60 per cent of the total. Included are the well-known salts, organic compounds, vermilion, acetic acid and dyestuffs. While the rate is small, normally these uses are decreasing. Fulminate no longer is the only detonator.

Electrical uses call for about 8 per cent but the most important—diffusion lamps and cells for the production of caustic soda and chlorine—are experiencing wider application. Battery zincs, arc rectifiers and miscellaneous uses are included in this group. The mechanical field which embraces meters, barometers, hydrometers, thermometers, gages, thermostats and pressure control devices accounts for about 13 per cent of the total.

In addition to these three general classifications the preparation of hatters felt—consuming over 10 per cent of the total—gold amalgamation, dental amalgams, alloys and laboratory uses make up the total from which, however, has been excluded the mercury boiler whose installation and, hence, use of mercury is not assessable to any one year. In this boiler present usage calls for about 7 pounds per Kw. which multiplied by 40,000 or 50,000 is a ponderable item.

As a whole, the consuming industries are fairly constant in the quantity used, those whose use is declining being offset by others whose demand is increasing. Mercury's value in war-time is no longer its use as a detonator, which use, however, can increase a thousandfold over peace-time requirements, but in its definite irreplaceable position in industries which affect safety, health and the daily life of all persons. We shall probably experience new uses, discard others but its value has existed for centuries. Its future may be altered in aspect but not in demand.

MISCELLANEA OF INTEREST TO NAVAL ENGINEERS.

THE GENERATION OF VERY HEAVY DIRECT CURRENTS BY MEANS OF UNIPOLAR MACHINES.—There is a growing demand in certain industries for low-voltage generators, of a range of a few volts, but producing very heavy currents, up to 100,000 amperes and more. Unipolar machines have proved very suitable for the purposes in question. Their simple design and good efficiency are sufficiently advantageous qualities to warrant a wider field of application being sought for them. This article is reprinted from The Brown Boveri Review, August, 1940, issue, published by Brown Boveri & Co., Ltd., Baden, Switzerland.

I. FIELD OF APPLICATION.

Efforts are constantly directed towards improving the machinery and equipment necessary for carrying out industrial processes, so that they may keep pace with the constant progress of technology and the resultant improvements of the industrial processes themselves. Economy in exploitation

can, for example, be realized by increasing production, or output or by shortening the time necessary for carrying out certain working processes. If it be a question of purely electrical processes, the voltage and the current are the main factors for increasing the output. Now, in electrolytic processes, the voltages which are usually necessary to overcome the internal resistance of the electrolytic cell are relatively low and of the order of a few volts only, while the currents necessary are very heavy. It is true that, as a rule, several cells are connected in series in order that the genrators need not be of such low voltage. However, when cells are connected in series, they are all subjected to the same current strength, which, in certain cases, is undesirable. The tendency is towards the parallel connection of the cells if this is possible and also towards increasing their size and this created a demand for current generators to produce very heavy currents at low voltages. This requirement is also encountered in industrial galvanizing plants, in electric melting furnaces (aluminum) and in butt welding (butt welding of pipes, etc.) where progress achieved has created a demand for constantly heavier currents, up to 100,000 A at a few volts.

II. DESIGNS.

Brown Boveri turned their attention, years ago, to the design of these machines, having recognized the growing demand for them. It is true that low-voltage direct-current generators for the exceptionally high current strengths of 10,000 to 15,000 A have been designed and built and have given satisfactory results in practice; however, they will hardly prove suitable to meet the requirements of the rapidly developing electro-chemical industry especially in view of its future possibilities. It, therefore, became necessary to seek a new solution which would not only provide the reliability essential to such important plants but would be economically advantageous as compared to the earlier designs of heavy-current generators of such low voltages.

The unipolar machine meets these requirements. It had been known for many years but its development was retarded partly because the demand for such heavy currents was not so great in former years as it has now become and partly because of the serious brush difficulties encountered.

As a matter of general interest, it may be mentioned here that as early as 50 years ago, C. E. L. Brown, one of the founders of our firm, made a careful study of the unipolar machine as a generator of heavy currents (see Figure 1), while Poirson exhibited a more modern design of the unipolar machine at the Paris Exhibition of 1937, this being a unit of 14 V and 50,000 A.

In the meantime Brown Boveri were carrying out exhaustive and systematic investigations of the unipolar machine especially as regards the brush problem and the carrying off of the considerable quantities of heat the generation of which on the friction surfaces under the brushes cannot be avoided when such heavy currents are handled. They succeeded in developing the machine from a laboratory apparatus into a practical and reliable, heavy-current generator capable of meeting modern industrial demands.

III. WORKING PROCESS AND DESIGN.

The heavy-current unipolar machine built by Brown Boveri is based on the principle of Faraday's discovery, in 1831, of the unipolar induction produced by a permanent bar magnet rotating round its axis. This showed that a galvonometer connected between two brushes one of which pressed on the surface and the other on the axis, was subjected to a constant deviation always in the same sense (Figure 2). The generation of the e. m. f. necessary to produce this deviation can be explained by the fact that every

rotating radius of material intersects in its movement the lines of force of the stationary pole N. This e. m. f. is tapped by the stationary brushes b_1 and b_2. This principle leads to a relatively simple design of direct-current machine without a commutator.

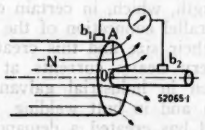


Fig. 2. — Diagram of the induction circuit in a rotating bar magnet.

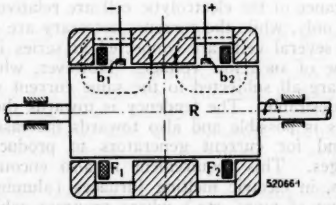


Fig. 3. — Diagrammatic representation of a unipolar machine.

The magnetic structure of the unipolar machine corresponds approximately to that shown in Figure 3. F_1 and F_2 are the field coils mounted concentrically to the shaft of the machine. These field coils generate two identical magnetic fields in the magnetic circuit surrounding them, the sense and circuit of which is marked by dashed lines. The electrically conductive rotor body R itself serves, here, as armature conductor. The brushes b_1 and b_2 in contact with the rotor body are lodged in the same slots in which the field coils are placed. These brushes can be distributed round the circumference of the rotor in any desired number. Generation of the e. m. f. is similar to what is shown in Figure 2 namely by the conductors formed by the material between the brushes b_1 and b_2 intersecting the fixed lines of force.

The design of a machine of this kind is extremely simple and the machine is very strong, thanks to the elimination of a rotating winding and of a commutator. The rotor, which is at the same time the only conductor subjected to induction, is composed of a massive forged steel cylinder with shaft ends flanged on. As, despite its rotation, there is never a change in the strength or sense of the field in the rotor no iron losses occur in ordinary service. The heat losses generated by the current passing through the rotor are negligible thanks to the very big section of the metal in relation to the strength of the current, this despite the relatively high specific resistance of steel as compared to copper. The only rotor losses of any magnitude are those generated at the brush contacts themselves and those caused by the friction of the brushes.

Very thorough tests carried out before machines of this type were built showed that if suitable brushes are chosen and if the surfaces on which the brushes press are properly prepared, there is no drawback in using the rotor material itself (steel in this case) as contact surfaces. This fact and the elimination of all soldered, welded or bolted current-carrying parts between conductor and slip rings makes for great simplicity and reliability.

To carry off the losses which are chiefly generated at the contact surfaces of the brushes a very effective system of water circulation in the rotor is used, a patent for which has been applied for. The amount of cooling water required is very small, because cooling of the regions in close proximity to the slip rings is direct and very effective and also because the specific heat of this cooling medium is high.

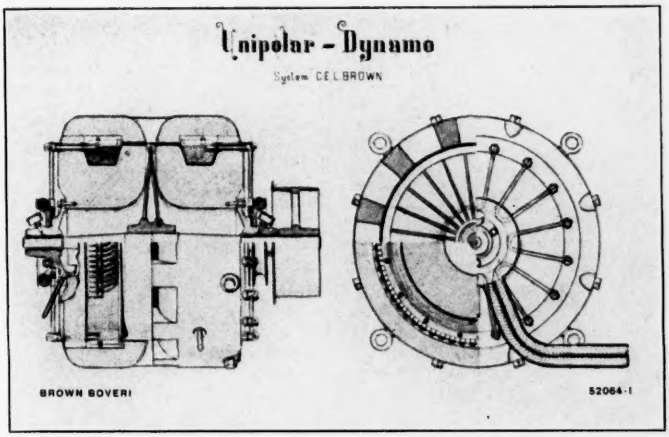


FIGURE 1.—UNIPOLAR MACHINE, 10 V, 2000 A, OF THE YEAR 1889, DESIGNED BY C. E. L. BROWN.

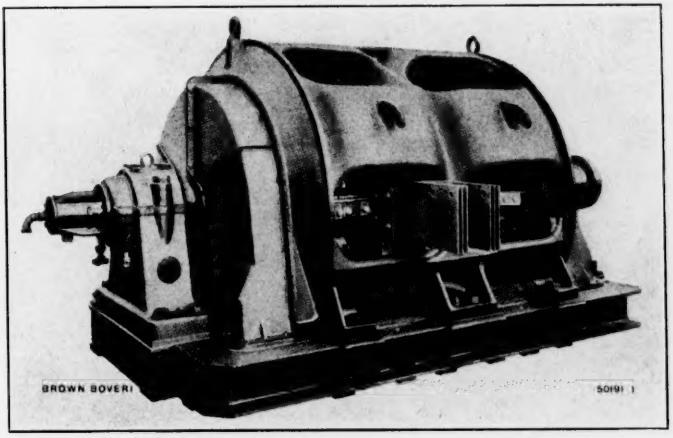


FIGURE 4.—UNIPOLAR MACHINE FOR 15 V, 30,000 A.

With many types of carbon brushes, the production of carbon dust is unavoidable, and for this reason separate ventilating devices are used, when necessary.

In order to isolate electrically the rotor—which also serves as armature conductor—from the ground, the bearing pedestals are insulated. The drive is also through insulating couplings. This insulation presents no difficulties at all as the voltages under consideration are relatively low.

The field windings can be built for auto-excitation or for separate excitation. In both cases, they consist of relatively big copper sections with a few turns only, because of the low excitation voltage. This results in very strong windings easy to insulate. Thanks to the possibility offered by separate excitation of using lower current strengths, which means a smaller field rheostat, separate excitation is preferable.

Figure 4 shows a unipolar machine built to these principles and which has been in constant service for a considerable period, now.

IV. EFFICIENCY.

From the economic point of view, the unipolar machine offers considerable advantages as compared to the ordinary low-voltage generator. Its efficiency is higher; thus, for example, while the efficiency of a unipolar machine of 15 V, 30,000 A is about 87.5 per cent that of an ordinary low-voltaged d.-c. generator with commutator will hardly come up to 80 per cent. As already mentioned, there are, usually, no iron losses to be considered in a unipolar machine. The excitation losses are relatively low as a result of there being no slots in the rotor with resultant high saturation of the teeth. Further, the bearing and ventilation losses are low, as compared to commutator machines which generally have powerful fans mounted on the rotor to cool the windings and especially the commutator. As was said before, in the unipolar machine developed by Brown Boveri, cooling of the surfaces under the brushes is by water circulation in the body of the rotor. The only losses of importance are those in the brush contacts and those due to brush friction. These losses vary with the material of which the brushes are made and with the circumferential speed of the friction surfaces under the brushes. As average value for the total losses, expressed in watts, at full load, double the strength of the current in amperes can be reckoned with. This allows of calculating the approximate efficiency for every voltage chosen, at full load.

V. FUTURE DEVELOPMENTS.

As already mentioned, unipolar machines can be used for electrolytic purposes, when low voltages and very heavy currents are required. The unipolar machine, designed according to the principle described in this article, can also be built for somewhat higher voltages with peripheral speeds of the rotor which are still within a relatively easily realizable range. The magnetic dimensions of the machine, however, then become so disadvantageous that the amount of material necessary is no longer in any reasonable relation to the simplification attained by adopting a unipolar design. In Figure 5, the vertically shaded surface shows approximately the voltage and current ranges of normal unipolar machines which are possible, today. The approximate efficiencies for the lower and upper voltage limit in function of the current are also given, this for the output range represented by shading. As will be seen, these efficiencies attain values which make the machine a sufficiently interesting proposition, from about 250 Kw. upwards, to make it worth while seeking new applications for it, in the field of electro-chemistry

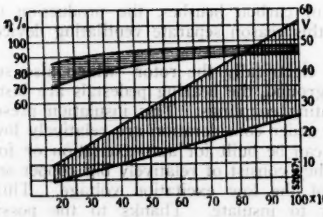


Fig. 5. — Practical current and voltage range of unipolar machines (vertical shading) with the efficiencies belonging thereto (horizontal shading).

and butt welding. The development of unipolar machines has reached the point where they can be substituted in industry, advantageously, for commutator machines of low voltage. Here, as well, further progress will certainly be made, based on practical experience.

BACK TO AIR INJECTION?—The reader may not agree with the conclusions of Warren Noble, Consulting Engineer, as presented in the following article but at least they contain food for thought. Have mechanical handicaps pushed Dr. Diesel's ideal, the air injection engine, into the background? This article is reprinted from the December, 1940, issue of Power, published by McGraw-Hill Publishing Co., 330 West 42nd St., New York, N. Y.

The columns of Power refer with regularity—properly speaking, with irregularity—to "Diesel" engines. Actually, there are relatively few true Diesels in the U. S. A., and I think none now in manufacture. Engines injecting fuel to the combustion chamber by jerk pump are *compression-ignition* engines having characteristics of their own definitely apart from the maintained-pressure principle evolved by Dr. Diesel.

He would be the last man to countenance the use of his name to designate a type he deprecated. Though, as a good engineer devoted to research, he made experiments with solid injection, he continued to the last to extol the virtues of his original air blast for fuel delivery. I shall speak of Diesel engines and principles only when dealing with such engines and refer to those using solid injection as CI engines.

DR. DIESEL'S AIM.

Diesel definitely aimed at maintaining the compression-pressure peak over a period of working stroke consonant with load, but without increase in pressure. While the CI engine would like to—and does at times—approach the same desirable condition, it cannot avoid some rise in pressure at the beginning of fuel injection. The Diesel engine depends on a supply of air, compressed beyond the pressure generated in the cylinder on the compression stroke, to atomize and deliver into the combustion space fuel metered to an open nozzle.

In the CI engine, a hydraulic pump drives the metered fuel directly into the cylinder, atomization being accomplished by expenditure of energy at the

injection orifice. This latter point is highly important, rarely recognized, and responsible for a great many of the CI engine's vagaries. This is not to say that air injection is without its foibles too, but they are due far more to causes exterior to the cylinder, in fact almost entirely so.

If we imagine two engines similar in all respects except as to this injection business, we can compare the practical setups best by contrasting the difference in the auxiliaries devoted to injection and starting. In the case of the Diesel, we must have an air compressor capable of creating a reserve of air at substantially double the engine-compression pressure, the distributing valve gear necessarily located at each cylinder, and the injection nozzles. The compressor need not be large. It will provide power for starting, but must be alternately driven or paralleled by a separate compressor if the engine is large. There must also be a metering device operating at low pressure.

The CI engine must have a starting system. If this is pneumatic, it requires a compressor as for the Diesel, although high-pressure capacity is not needed; if electric, a high-torque motor, storage batteries and a charging generator are required. There must be nozzles at the cylinders, to which the metered fuel can be piped, and there must be a high-pressure metering hydraulic pump.

In everyday practice this metering pump is looked upon as the heart of the engine—actually it can be rated only in company with its nozzles since final performance depends on the end result of pump and nozzle in combination. Usually the complete assembly is purchased from a specialist manufacturer who supplies—and so types for performance—injection systems for many engine builders. The manufacture of such a metering pump and nozzles is probably the highest expression of associated precision parts extant. Few organizations can aggregate the necessary skill to make and maintain the necessary quality of mechanism, and the cost of these units constitutes an important element of engine cost.

In the Diesel proper, the metering function needs to be held to corresponding accuracy, although high-pressure delivery is not involved. Actually there is little advantage or comfort in this pressure change since metering of a viscous liquid such as fuel oil involves a quality of workmanship beyond normal, so far beyond in fact that the high- or low-pressure factor can be neglected.

AIR-COMPRESSOR PROBLEMS.

Construction of multi-stage air compressors capable of reliable operation over long periods of time, while delivering air in the neighborhood of 1200 pounds per square inch, is a task of no mean magnitude. The history of the Diesel engine in practice is a long record of air-compressor problems. Valve gear and nozzles in general present no difficulty, so that in the end we find the true Diesel picture dimmed by compressor difficulties.

Now, the quality of Diesel or CI cylinder performance depends directly on the quality of fuel atomization. Improve distribution of fuel through the air charge and the performance will improve correspondingly. The fuel as it leaves the nozzle hunts oxygen, the surrounding air is heated, and power generation begins. Each drop of fuel burns on its own; acts like a burning bullet. But unfortunately, as it burns it surrounds itself with a jacket of burned gas, slows down on its oxygen hunt and even has difficulty satisfying its fire-feeding hunger.

IF WE HAD A DUAL FUEL.

It would be plain sailing if a droplet of fuel could be made to act like a rocket, once fired self-propulsive. Or, if we could only use a dual fuel in

which a coat of slowly combustible oil contained a nucleus of highly evaporative inflammable. The initial combustion would cause the nucleus to burst through the coating, scattering it in all directions. In other words, if we could arrange for the particle or droplet of fuel to carry some dispersive energy along with it, combustion would change markedly for the better. As things are now, the work done by the jerk pump expends itself first in atomizing the oil indifferently well, leaving but little surplus energy to secure penetration into the dense air of the combustion chamber.

It is this part of the picture that turns me back to Diesel's method where the metered mass of oil is atomized and carried along by high-velocity air. The final droplet is definitely finer, which means more surface available to the hungry air, although on account of the expansion of the carrier air it is robbed of some heat. However, this air has to come through the nozzle, and so picks up some heat to help regenerative action. The expanding air, moreover, has potential energy with which to carry oil droplets along, rolling them tornado-wise like a barrel in the rapids. Furthermore, a high degree of combustion-space air turbulence is set up, in addition to the turbulence inherent in the space form and aimed at by the engine designer. Even the cooling effect of the injection air has beneficial function in fighting detonation—the bugbear of CI-engine as of gasoline-engine design.

A NEW COMPRESSOR DESIGN.

I am perfectly convinced better atomization and better all around performance lie ready to command in the air-injection engine. This is in the face of the facts, which begin and end with a wide collection of satisfactory engines of which none employs an air blast for injection purposes.

To my way of thinking, the compressor is to blame for the trend away from the air-injection engine. It represents another complication for designer and operator alike. But let's see whether we might not be able to get along without said compressor in its conventional form. If we start to design an independent compressor for 1200-lb. air, we certainly need three, and probably four, stages. However, the condition is different when we design a compressor for a Diesel engine, because we already have available within each cylinder a perfectly good compressor, working up to the equivalent of the third stage of any compressor we might build.

Suppose then—remember I'm simply thinking out loud—we bleed off from our combustion space, just prior to injection, or after, for that matter, a small quantity of air sufficient for the nozzle blast. Let's run it through an intercooler (the conducting pipe will probably be plenty good enough to drop temperature) leaving pressure at about 400 pounds. Let's make a combination nozzle and measuring pump, fed from a common rail, and a step-up air cylinder drawing its charge from the 400-pound cooled air bled from the main cylinders themselves. Let's operate the combination pump, nozzle and compressor from the camshaft, with a lift and rocker arm, just as we now do the valves or the injection lift on any present-day common-rail system.

Down will go the rocker, super-compressing the bled air to whatever we need in the way of blast pressure; at the right moment, let trapped high-pressure air and measured fuel through to the combustion space. We should have everything the Diesel system gave us, less the unit compressor and with no more valve gear than we normally have today. Certainly we shall have provided some extra turbulence, arranged for better atomization than a direct jerk-pump-fed nozzle can give us, and saved a lot of compressor mechanism. We shall need a bigger main cylinder—infinitesimally so di-

mensionally speaking—with a slightly higher prime compression ratio. But don't forget some of the energy of the injection air is recovered on the working stroke; it's not all loss by any means.

The more I think of it the better I like it. I believe the scheme would relieve the CI sluggishness as compared with the true Diesel, get rid of nozzle troubles and be adaptable for use in small engine sizes (in which the volume of business lies), never within reach of true Diesel methods.

MODULUS OF ELASTICITY OF ALLOYS.—Reprinted from the August, 1940, issue of The Metallurgist, supplement to the October 25, 1940, issue of The Engineer, published temporarily at 18 Compton Road, Hays, Middlesex, England.

The stiffness of beams and other structural members is dependent on the modulus of elasticity of the materials employed, and this property has become increasingly important to designers with the continual improvement in the strength of alloys which has provided engineers with the possibility of greater lightness of construction.

Alloy steels are capable of supporting higher working stresses than mild steel, but within the safe working stresses their use confers no increase in rigidity. The elastic moduli of all steels are approximately equal, and if a certain elastic deflection must not be exceeded in a structure, alloy steels offer no saving in weight over mild steel. The sections employed must be the same for each material. The modulus of a light alloy is to that of steel in the approximate ratio of their densities. Hence, aluminum alloy beams must be deeper than corresponding steel beams to preserve the same stiffness. This sometimes means that the high strength of certain light alloys cannot be completely utilized because of limitations in the permissible deflection under load.

TABLE I.—*Modulus of Elasticity of the Metals*

	Atomic volume.	Melting point, deg. Cent.	Modulus of elasticity.	
			Kilos. per sq. mm.	Lb. per sq. in.
Tungsten ...	9·6	3,660	42,000	$59·7 \times 10^6$
Beryllium ...	4·9	1,278	36,000	51·2
Iron...	7·1	1,530	21,000	29·8
Nickel	6·6	1,451	22,000	31·3
Platinum ...	9·1	1,771	16,300	23·2
Copper	7·1	1,083	12,600	17·9
Silicon	12·2	1,425	9,500	13·5
Gold	10·2	1,063	8,500	12·1
Zinc...	9·2	420	8,000	11·4
Silver	10·2	961	7,000	10·0
Aluminium ...	9·9	658	7,300	10·4
Magnesium ...	13·9	651	4,500	6·4
Tin	16·3	232	4,000	5·7
Calcium	26	809	2,000	2·8
Lead	19	327	1,800	2·6

TABLE II.—*Modulus of Elasticity of Copper Alloys*

Copper-Aluminium.			Copper-Zinc.			Copper-Tin.		
Al, per cent.	Modulus of elasticity.		Zn, per cent.	Modulus of elasticity.		Sn, per cent.	Modulus of elasticity.	
	Kilos. per square mm.	Lb. per square in.		Kilos. per square mm.	Lb. per square in.		Kilos. per square mm.	Lb. per square in.
0	12,600	$17{\cdot}9\times10^6$	0	12,600	$17{\cdot}9\times10^6$	0	12,600	$17{\cdot}9\times10^6$
2·05	12,260	17·4	9·79	12,060	17·1	1·92	12,300	17·5
4·72	11,920	17·0	19·36	11,600	16·5	3·81	12,000	17·1
5·80	11,750	16·7	25·25	11,380	16·2	6·05	11,620	16·5
7·90	11,650	16·5	34·76	10,970	15·6	8·02	11,350	16·1
9·87	11,350	16·1	37·33	10,830	15·4	9·90	10,900	15·5

TABLE III.—*Modulus of Elasticity of Light Alloys*

Aluminium-Copper.			Aluminium-Magnesium.			Magnesium-Aluminium.		
Cu, per cent.	Modulus of elasticity.		Mg, per cent.	Modulus of elasticity.		Al, per cent.	Modulus of elasticity.	
	Kilos. per square mm.	Lb. per square in.		Kilos. per square mm.	Lb. per square in.		Kilos. per square mm.	Lb. per square in.
0	7,300	$10{\cdot}38\times10^6$	0	7,300	$10{\cdot}38\times10^6$	0	4,500	$6{\cdot}40\times10^6$
2·18	7,300	10·38	2·29	7,240	10·30	2·10	4,660	6·63
2·58	7,480	10·64	4·18	7,280	10·35	4·58	4,720	6·71
6·47	7,500	10·67	5·80	7,300	10·38	6·88	4,750	6·75
7·90	7,620	10·84	8·00	7,200	10·24	8·00	4,830	6·87
10·20	7,680	10·92	10·07	7,150	10·17	9·28	4,790	6·79
12·85	8,030	11·42	11·93	7,120	10·13	12·15	4,860	6·91

A comprehensive experimental study of the modulus of elasticity of metals and alloys has been made by L. Guillet, jun.* The modulus in tension was determined by the Rolland-Sorin method, which depends on the sympathetic vibration of two equal pendulums hanging from the ends of a short platform secured to the bottom of the test specimen which is clamped in a vertical position at the upper end. While one pendulum (P1) is stationary, the other (P2) is set in motion. The oscillations of P2 diminish, while those of P1 increase to a maximum at the moment when P2 is stationary, and then die away again as those of P2 increase. If t is the time between two successive stationary conditions of the pendulum P1 and E is the modulus of elasticity of the test specimen, then $E = k\,t$. The value of the constant k is determined by calibrating the instrument by tests on metals of known elastic modulus; for example, aluminum, copper, platinum, and mild steel. The calibration curve of modulus against time interval between stationary conditions is a straight line, and the value of E, for an observed value of t, can be readily ascertained. The method has the advantage that small specimens can be used. The bars employed were 60 millimeters long and 5·64 millimeters in diameter, or 25 square millimeters in cross sectional area. Cast bars were radiographed before they were tested to ensure that sound material was being used.

The values obtained for the moduli of the metals are given in Table I, together with the atomic volumes V and the melting points T. The modulus E, plotted against $1/V^2$, gives points scattered about an approximate straight line. If E is plotted against T/V^2 the scatter is reduced, but the relation is far from accurate, and merely indicates that a high modulus is to be found in elements of high melting point, whose atomic value is low. Although the modulus of beryllium was known by the atomic volume relation to be high and in the vicinity of 30,000 kilometers per square millimeter, the value given in the table is claimed to be the first experimental determination of the value for metallic beryllium, the density of which was found to be 1·85. The sample contained about 97·8 per cent of beryllium.

The alloys investigated included the solid solutions of copper with zinc, aluminum, and tin. In each case the alloy addition regularly diminishes the modulus of copper. The reduction in modulus was a linear function of the tin or zinc content, and also of aluminum content when this was expressed as per cent by volume. Addition of iridium or of rhodium to platinum increased the modulus, again in an approximately linear manner. The value 16,300 kilometers per square millimeter for platinum was raised to 20,300 kilometers and 21,850 kilometers per square millimeter by the addition of 15 per cent of iridium and of rhodium respectively.

Intermetallic compounds fell into two groups:—(1) Those with metallic characteristics in which the modulus agreed with that calculated by the law of mixtures, *e. g.*, CuZn, $CuAl_2$, CuAu, etc.; and (2) the homopolar compounds, such as Cu_5Zn_8, $Cu_{31}Sn_8$ in which the modulus was considerably higher than the value calculated in this way, and in some instances higher than that of either constituent. For example, Cu_9Al_4 (copper 84·25 per cent) had a modulus of 16,850 kilometers per square millimeter. All such compounds, however, are extremely brittle.

Alloys consisting of two phases, *e. g.*, a solid solution and a compound, also showed a linear relation between the two phases. Berryllium causes a marked rise in the modulus of copper, thus:—

* Revue de Métallurgie, December, 1939, 36, 497.

Beryllium, per cent	*Modulus of elasticity, kilos. per sq. mm.*	*lb. per sq. in.*
0	12,600	$17{\cdot}9 \times 10^6$
4·6	14,500	20·6
10·6	17,000	24·2
12·4 (CuBe)	18,000	25·6
16·6	20,400	29·0
22·1 ($CuBe_2$)	22,800	32·4

Other examples are given in Table III. The effect of aluminum and magnesium on one another is very slight. Copper raises the modulus of aluminum continuously up to 45·7 per cent ($CuAl_2$), when the value is 9640 kilometers per square millimeter, and over the whole range of composition, aluminum to copper, there were abrupt changes in direction of the modulus curve when the two phases changed, with a maximum at Cu_9Al_4, as indicated above.

The influence of heat treatment on the modulus was studied. In the commercially important alloys the modulus was very little affected by heat treatment, but in alloys containing intermetallic compounds changes could be brought about which affected the modulus considerably. For example, the suppression of the separation of $Cu_{31}Sn_8$ by quenching copper-tin alloys with 22 to 32 per cent of tin caused a considerable reduction in the modulus which reverted to its original value on reheating. On the other hand, the variation in modulus obtained by quenching and tempering a 2·5 per cent beryllium-copper alloy was only about 6 per cent, the values obtained being as follows:—

	Brinell hardness number	*Modulus of elasticity, kilos. per square mm.*
Water-quenched from 800 deg. Cent.	120	12,600
Reheated 3 hours at 320 deg. Cent. and slowly cooled	360	13,570

The increase in modulus produced by temper hardening is thus less than has sometimes been suggested.

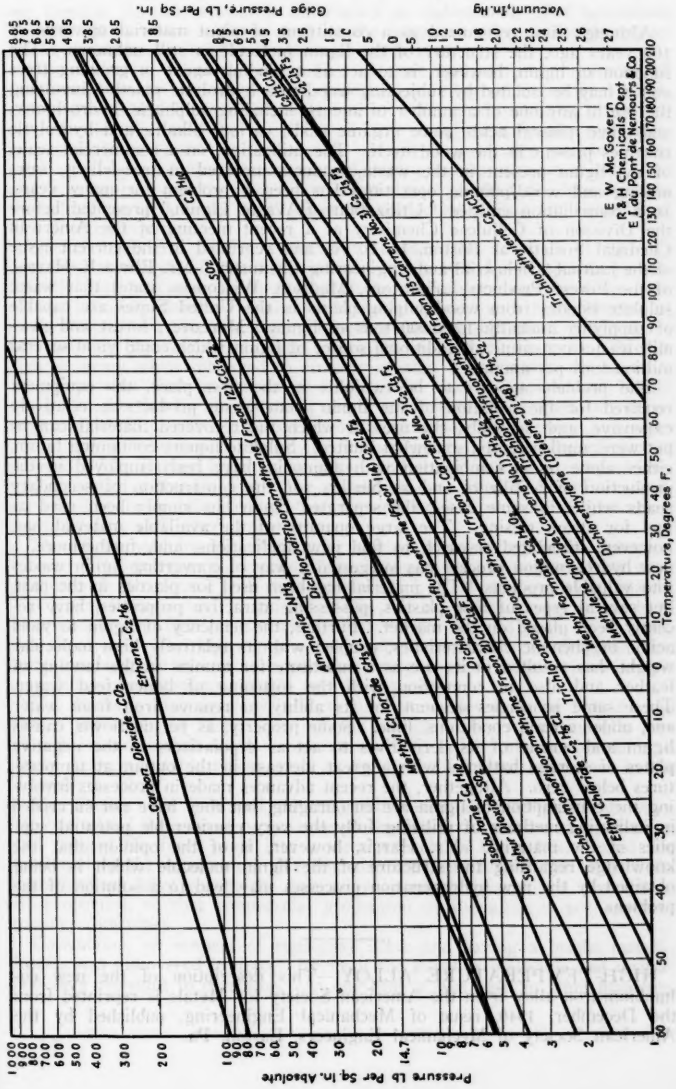
In a 0·83 beryllium-aluminum alloy the change in modulus on ageing was even smaller:—

	Brinell hardness number	*Modulus of elasticity, kilos. per square mm.*
Water-quenched from 630 deg. Cent.	25	7500
Aged	40	7600

Ageing of this alloy takes place very rapidly, being complete in about one hour at room temperature.

The investigation, in addition to providing some useful data on the influence of composition on the modulus of elasticity of commercial alloys, has confirmed the widely held conclusion that small variations of composition and the presence of impurities have a negligible effect on the modulus of elasticity of a metal or alloy. Except in certain series of solid solutions, exemplified by the platinum-rhodium alloys, it would appear to be impossible to effect a notable improvement in the modulus of elasticity of a metal by alloy additions, since even if the added element itself has a high modulus, its presence in quantities sufficient to produce a substantial increase in the modulus is usually accompanied by phase changes which render the alloy unsuitable for commercial purposes.

PRESSURE-TEMPERATURE CHART FOR REFRIGERANTS.—This chart showing pressure-temperature characteristics of the most commonly used refrigerants is reprinted from the January, 1940, issue of Power, published by the McGraw-Hill Publishing Co., 330 West 42nd St., New York.


Gage Pressure, Lb Per Sq In.
Vacuum, In. Hg
Pressure Lb Per Sq In. Absolute
Temperature, Degrees F.
Carbon Dioxide - CO2
Ethane - C2H6
Ammonia - NH3
Dichlorodifluoromethane (Freon) - CCl2F2
Methyl Chloride - CH3Cl
Dichloromonofluoromethane (Freon 21) - CHCl2F
Dichloromonofluoromethane (Freon 141) - C2H3Cl2F
Isobutane - C4H10
Sulphur Dioxide - SO2
Dichloromonofluoromethane (Freon 22) - CHClF2
Trichloromonofluoromethane (Freon) - CCl3F
Methyl Formate - C2H4O2
Ethyl Chloride - C2H5Cl
Methylene Chloride - CH2Cl2
Dichloroethylene
Trichloroethylene - C2HCl3
E. W. McGovern
R. & H. Chemicals Dept
E. I. du Pont de Nemours & Co

PRESSURE-TEMPERATURE CHART FOR REFRIGERANTS.

THE UTILIZATION OF WASTE LIGNIN.—Reprinted from the September 6, 1940, issue of Engineering, temporarily published at 18 Compton Road, Hays, Middlesex, England.

Although first recognized as a constituent of plant material upwards of 100 years ago, the structure of the lignin molecule is still unknown. The function of lignin, however, is to act as a binding agent in growing trees and it may be isolated by subjecting wood to a hydrolytic reaction involving the use of any one of a number of agents, including sulphuric, hydrochloric, and other mineral acids, some organic acids, various alkalis, and hydrolytic enzymes present in the wood itself. The utilization, on a commercial scale, of the lignin present in the waste products incurred in tree-felling, sawmilling and wood-pulping operations has been a problem for many years. In a contribution entitled "Utilization of Waste Lignin," presented before the Division of Cellulose Chemistry at a recent meeting of the American Chemical Society, at Boston, U. S. A., and reprinted in the current issue of the journal "Industrial and Engineering Chemistry," Mr. Elwin E. Harris, of the Forest Products Laboratory, Madison, Wisconsin, states that waste sulphite liquors from wood-pulping plants in the United States are capable of supplying annually 1,500,000 tons of lignin. Moreover, forest and sawmill wastes constitute an additional source of lignin which could yield several million tons per annum.

The problem appears to be twofold: in the first place, the equipment required for the isolation of the lignin from waste products is relatively expensive, and, secondly, the uses to which the recovered material can be put were, until recently, somewhat limited. Sulphite liquors containing lignin, either alone or in combination with ammonia, have been employed in the production of fertilizers and as binders for the construction of secondary roads while, in some cases, the separated lignin has simply been used as fuel for steam raising. The large quantity of the available material has, however, stimulated research to find new applications, and, furthermore, a new hydrogenation process has suggested a way of converting lignin wastes into valuable products. The material has been used for plastics in the past, but several types of new plastics, possessing attractive properties, have recently been placed on the market. Further, the tendency of lignin to yield acidic or phenolic characteristics, coupled with its relatively high molecular weight, has resulted in its use as a substitute for tannins in the tanning of leather and also in connection with the softening of boiler feed water. These same properties account for its ability to remove iron from water and, under certain conditions, lime. Some property, as yet unknown, causes lignin and certain of its derivatives to act as depolarizers in the negative plates of storage batteries with a great increase in the output at temperatures below zero. Altogether, the recent advances made in processes involving the consumption of lignin are encouraging, but they have not succeeded in indicating methods of utilizing fully the very considerable potential supplies of the material. Mr. Harris, however, is of the opinion that the knowledge regarding the structure of the lignin molecule which is being obtained by the new hydrogenation processes may lead to a solution of the problem.

HIGH-TEMPERATURE ALLOY.—This description of the new columbium-iron alloy from the American Society for Metals is reprinted from the December, 1940, issue of Mechanical Engineering, published by the American Society of Mechanical Engineers, Easton, Pa.

A new alloy may make it possible to extend further the temperature at which steam turbines are operated, without involving the expensive steels which seemed necessary before the new alloy was produced. E. R. Parker of the General Electric Research Laboratory at Schenectady first announced the new alloy, which is not a steel, at the annual meeting of the American Society for Metals, in Cleveland, October 21, 1940.

Columbium, a relatively unfamiliar element and with a minimum of commercial importance at present, produces an alloy of exceptional properties when added in small amounts to iron. Samples containing three per cent of columbium and the remainder of iron reveal exceptionally good rupture strength at 1100 F., a temperature not yet commercially used but being approached by modern high-temperature, high-pressure steam turbines. No carbon is contained in the alloy, so it is not a steel; instead, the iron contains the columbium as a finely dispersed stable compound of iron and columbium, Mr. Parker reported.

Special steels are readily available to answer the demands of turbines operating at today's highest temperatures—about 1000 F.—temperatures sufficiently high to cause the metals to glow. Laboratory investigations have shown, however, that to continue with similar steels—with high contents of molbydenum, tungsten, vanadium, or such metals—would mean costly steels for turbines capable of successful operation at 1100 F. or more. Metals flow or creep when subjected to stresses at high temperatures—by amounts so minute that their measurement might seem hardly possible and hardly of significance, but by amounts that are of great importance when considered over the period of years a turbine remains continuously in service and when considered in relation to the precise measurements that turbine efficiencies demand. Mr. Parker investigated alloys and steels of known compositions, and continued with new ones. The columbium-iron alloy he found outstanding of all at the specified temperature, considering its cost, ease of production, machinability, and other properties.

The alloys used by Mr. Parker for testing were melted in an induction furnace. Room-temperature tensile tests, creep tests, and rupture tests were conducted in accordance with the approved A. S. T. M. and similar standards. The creep furnace used is somewhat like the many large ones which have been used by the General Electric Company more than 15 years in its creep investigations. The high-temperature rupture furnace is so designed that tests can be made in any atmosphere, it being possible to have each sample in a different atmosphere, should such be desirable.

Mr. Parker's investigations indicate that, at temperatures of 1100 F. and above, the strongest metals are not the carbide steels so successfully employed for somewhat lower temperatures but, rather, alloys containing a finely dispersed stable phase, such as the iron-columbium compound in the columbium alloy.

Mr. Parker has produced the columbium-iron alloy in different ways. He has mixed the correct proportions of the powdered metals, sintered them, and swaged the fused mass into a metal capable of being heat-treated and machined in the usual way. He has also cast and forged the alloy. His investigations have shown the cast alloy to equal the sintered material in its properties, so that commercial production of the alloy is not expected to offer difficulties.

Columbium, an element of steel-gray color and having a bright metallic lustre, was discovered in 1801. By itself the metal is malleable and ductile, and very resistant to corrosion. At one time it was used in lamp filaments,

and it is used in jewelry. There is also a columbium-stabilized 18-8 (stainless) steel in which the columbium forms a carbide. The element does not occur in the free state, and its minerals are relatively rare. Only a small tonnage of columbium is produced annually, but with increased demand the supply could easily be increased. At present most of the commercial supply comes from Australia. However, it was in ore of American origin—and hence columbium—that the element was first discovered.

WHAT DIET FOR YOUR DIESEL?—S. S. Hansen, Chief Lubrication Engineer, General Petroleum Corporation, discusses proper fuel and lubricating oil for Diesel engines in this article reprinted from the August, 1940, issue of Power, published by McGraw-Hill Publishing Co., 330 West 43rd Street, New York, N. Y.

It's possible to burn almost any liquid fuel in a Diesel, but every operator knows that a more or less narrow range of fuels gives best results on a particular engine. Likewise, every operator knows that some lubricating oils do better jobs than others. However, the rub comes when we face the job of finding the right diet of fuel and lube oil for the engines in a particular plant. There aren't any hard and fast rules, so the operator must know how the various oil characteristics affect engine performance and how to weigh their importance in his own case.

Table I lists the most important characteristics of a Diesel fuel which must be considered in determining its quality, and gives recommendations as to the general class of fuel suitable for various engine types. However, the first physical characteristic of a fuel which must be given practical consideration is its "pumpability" at the lowest atmospheric temperature at which it is intended to be used. Table II defines specific temperatures at which Diesel fuels, of both naphthenic and paraffinic types, may be safely handled.

CONSIDER VISCOSITY.

After the operator has checked the practicability of using a certain fuel from the standpoint of pumping, he should consider the fuel's viscosity. This, of course, bears a close relation to pumpability; that is, the viscosity should be low enough for the oil to flow freely at lowest probable temperature. On the other hand, the viscosity must be high enough so as to guarantee some lubricating value for the injection plungers and prevent leakage. In this connection, the lowest limit which should be set on a fuel is not less than 35 Saybolt sec at 100 F.

Viscosity also plays an important part in relation to atomization and penetration requirements of the combustion chamber. Thus a heavy fuel will usually penetrate deeper into the high-pressure air in the compression chamber than will a light fuel. This results from the fact that a heavy oil tends to maintain a more or less solid stream as it travels through the compressed air. A light fuel, on the other hand, tends to spread over a wide area through the combustion air and does not penetrate far enough for complete combustion. The ideal fuel presents a compromise between penetration and fogging or spreading. From this standpoint, the engine builder's recommendation represents the most reliable guide to fuel selection.

Ignition characteristics of different fuels vary greatly. Ignition quality is the ability to ignite spontaneously under the conditions existing in the engine cylinder. A fuel with good ignition quality, that is, one that will auto-ignite at low temperatures, is most desirable for Diesel engines, for

FIGURE 1—THIS PISTON FROM A LABORATORY TEST ENGINE OPERATED AT CONSTANT FULL LOAD FOR 108 HOURS WITH THE WRONG LUBRICATING OIL. NOTE THE HARD LACQUER-LIKE DEPOSITS AROUND THE TOP RINGS AND THE DARKENED PISTON SKIRT, WHICH ALSO GIVES EVIDENCE OF BLOWBY. FREEDOM FROM DEPOSITS AROUND THE OIL RING SHOWS THE EFFECT OF TEMPERATURE.

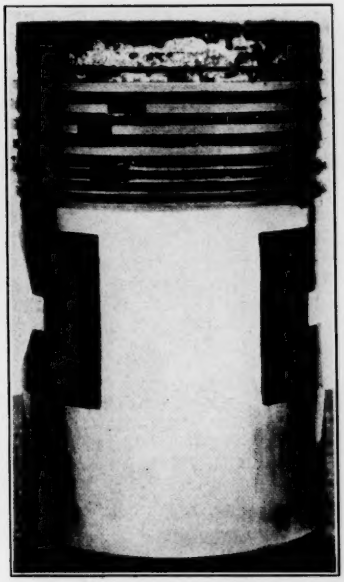


FIGURE 2.—THIS PISTON, ALSO TAKEN FROM A LABORATORY TEST ENGINE, OPERATED AT FULL LOAD FOR 1000 HOURS. NOTE THAT ALL RINGS ARE FREE IN THEIR GROOVES AND BEAR OUT AGAINST THE CYLINDER WALL AS SHOWN BY THE CLEAN, SHINY APPEARANCE OF THE RING.

several reasons. Ease of starting, smoking, and knocking all relate to a fuel's ignition quality. This obviously important property is usually measured in terms of the "cetane number." Let's see exactly what this term means and how it is measured.

As is well known, crude oil is one of the thousands of combinations formed by hydrogen and carbon. The hydrocarbon family ranges from such a simple combination as the gas methane (one hydrogen atom and four carbon atoms) to the liquid fractions which comprise fuels and lubricants and to the semi-solid and solid compounds which comprise waxes and asphaltic materials. Through this progression from gas, to liquid, to solid compounds, the number of atoms of hydrogen and carbon increases, the molecular weight also increases, and the chemical and physical properties change. One of these hydrocarbon families, having the chemical formula $C_{16}H_{34}$, is given the name "cetane."

Cetane in its purest form makes an excellent Diesel fuel but it is commercially impractical to separate completely the cetane family from other hydrocarbon families having similar boiling points. Cetane content also varies widely from one crude to another. Another hydrocarbon family, named alpha-methyl-napthalene, $C_{10}H_7CH_3$, having a similar boiling point to cetane, displays exceedingly poor ignition characteristics in Diesels. The proposed ASTM yardstick for measuring ignition quality of Diesel fuel, called the "cetane-number" scale, depends on the proportions of these two hydrocarbon families.

THE CETANE SCALE.

On this standard scale, cetane is 100 and alpha-methyl-napthalene is zero. Thus a "cetane number" of 100 means an ignition quality equal to that of pure cetane, while a cetane number of 0 indicates an ignition quality equal to that of alpha-methyl-napthalene. How about a number between? Well, a cetane number of 60 indicates an ignition quality equal to that of a mixture of 60 per cent cetane and 40 per cent alpha-methyl-napthalene. In other words, ignition quality of a fuel to be tested is compared to ignition qualities of standard mixtures of these two hydrocarbons. Although research workers have proposed several methods for measuring ignition quality on this cetane scale, the ignition-delay method, using a single-cylinder test engine, is widely employed.

On the test engine, a mechanism varies the compression ratio while other operating conditions are held constant. An electrical contact on the injection plunger measures the beginning of the "ignition-delay" period. When ignition of the fuel charge occurs, a diaphragm in the combustion chamber makes another contact. This gives time elapsing from injection to beginning of ignition, or "ignition-delay" period.

To determine the cetane number, the fuel to be tested is supplied to the engine and the compression ratio is varied until the ignition-delay period reaches a standard length. It can be seen that fuels of poor ignition quality require a high compression ratio to shorten the delay period to the standard length while fuels of good quality display shorter delay periods and so require lower compression ratios to obtain the standard delay. After finding and recording the compression ratio for the test fuel, the operator runs various mixtures of cetane and alpha-methyl-napthalene in the test engine, finding and recording the compression ratio required in each case to bring the delay period to the standard figure. The cetane number of the test fuel equals the percentage of cetane in the mixture that requires the same compression ratio as the test fuel to produce the standard delay period.

TABLE I—ASTM DIESEL-FUEL-OIL CLASSIFICATION

Grade of Fuel	*1-D*	*3-D*	*4-D*	*5-D*	*6-D*
Saybolt Universal Viscosity, at 100 F. min.	35	35	....	....	....
Saybolt Universal Viscosity, at 100 F. max.	50	70	250	....	....
Saybolt Furol Viscosity, at 122 F. max.	....	....	....	100	300
Pour point, F. max.	35	35	35	....	....
Cetane number	45	35	30	....	....
Diesel index*	45	30	20	....	....
Flash point, F. min.	115	150	150	150	150
Carbon residue, % by vol. max.	0.2	0.5	3.0	6-0	....
Ash, % by weight, max.	0.02	0.02	0.04	0.08	....
Sulphur, % by weight, max.	1.5	1.5	2.0	2.0	2.0
Water and sediment, % by vol.	0.05	0.1	0.6	1.0	....

$$\text{*Diesel Index} = \frac{\text{Aniline point, F.} \times \text{API. Gravity}}{100}$$

Aniline point is found by heating equal volumes of aniline and fuel oil in a jacketed test tube until a clear solution is obtained, and then noting the temperature at which turbidity appears on cooling.

ASTM DIESEL-FUEL RECOMMENDATIONS

Grade	*Type of Engine*
1-D	Solid-injection engines operating at more than 1000 rpm.
3-D	Solid-injection engines operating at from 360 to 1000 rpm.
4-D	Air-injection engines operating at less than 400 rpm.; solid-injection engines with cylinder dia. over 16 in., operating at less than 240 rpm.
5-D	Air-injection engines operating at less than 240 rpm.
6-D	Used only in isolated instances.

The foregoing indicates that if an operator expects peak performance from his Diesel, coupled with freedom from combustion difficulties, he must purchase fuels of good cetane rating.

Proper storage and handling of fuels cannot be over-emphasized. Numerous tests reveal that when galvanized tanks are used, minute particles of zinc and iron flake from the sides of the tank and contaminate the Diesel oil, causing severe wear of injection plungers, upper cylinder walls, pistons, and piston rings. Welded tanks of non-corrosive materials, such as copper-bearing steel, give best service. Preferably, tanks should be installed above ground, on a substantial foundation, with a slope of not less than ½ inch per foot of length and with the outlet 2¾ inches above the bottom. This arrangement insures that clean fuel will be drawn out while water, dirt, sediment, etc., sink to the bottom.

Diesel engine builders and oil companies have carried on intensive research during the past few years to learn more about the performance characteristics of various types of lubricating oils. Newly developed chemical addition agents have, in some cases, demonstrated their worth in retarding piston-ring deposits and improving the mineral oil's stability and "oiliness" characteristics. To date, no one compound or combination of compounds will give an oil all of the properties desirable in a perfect lubricant. In some engines a straight mineral oil, properly refined and properly selected, gives best results. Other engines, principally the smaller, high-speed types which employ precombustion chambers and which are sensitive to carbon formation, require special types of mineral oils with chemical addition agents.

However, intensive laboratory research and wide field experience proves one point conclusively. The Diesel operator who attempts to purchase lubricants on the basis of physical specifications follows a dangerous policy, one which does not have a sufficient basis in fact. Recent changes in refinery technique greatly alter performance characteristics of the finished oils. In times past, when lubricants were refined from only a few different types of crudes, by more or less conventional refining methods, the yardstick of oil specifications may have been a reasonably accurate guide to performance

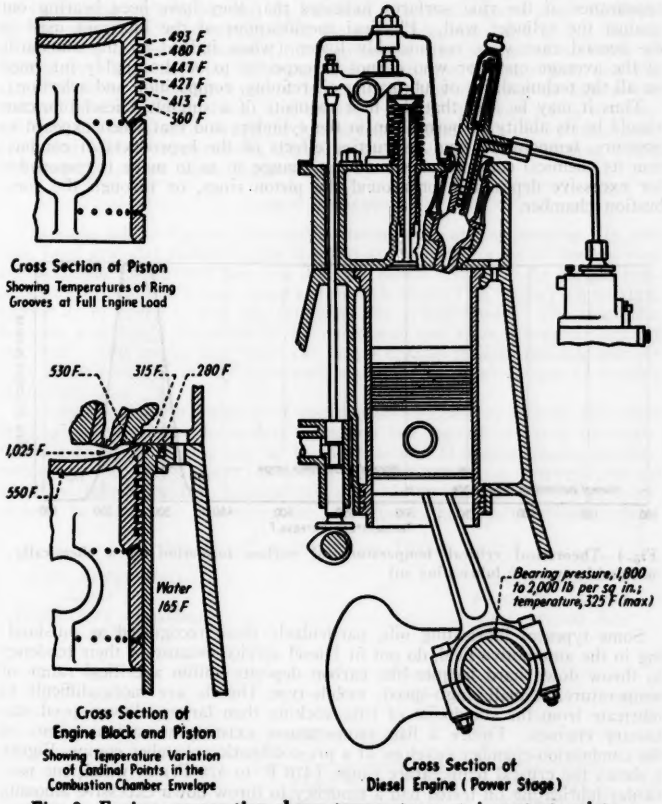

493 F
480 F
447 F
427 F
413 F
360 F
Cross Section of Piston
Showing Temperatures of Ring Grooves at Full Engine Load
530 F
315 F
280 F
1,025 F
550 F
Water 165 F
Cross Section of Engine Block and Piston
Showing Temperature Variation of Cardinal Points in the Combustion Chamber Envelope
Bearing pressure, 1,800 to 2,000 lb per sq in.; temperature, 325 F (max.)
Cross Section of Diesel Engine (Power Stage)

Fig. 3—Engine cross-section shows temperatures at important points

characteristics. This situation no longer holds. Sources of crude oil vary widely and the advent of solvent refining has completely revolutionized any slight relation that physical characteristics may once have had to an oil's service performance.

As an illustration of this point, consider the piston shown in Figure 1. This was taken from a laboratory test engine in which a lubricating oil of exceptionally high physical specifications (gravity, flash and fire points, neutralization number, and carbon content) was used. The 1-cylinder test engine, operating at constant full load, failed after 108 hours, due to excessive blowby. Study of the picture reveals that all top piston rings are stuck in their grooves by a lacquer-like deposit.

The piston shown in Figure 2 operated under identical conditions of service for 1000 hours. All rings remain clean and free in the grooves and the shiny appearance of the ring surfaces indicates that they have been bearing out against the cylinder wall. Physical specifications of the lubricant used in the second case were considerably lower (when judged by the standards of the average operator who cannot be expected to be thoroughly informed on all the technicalities of lubricating-oil refining, composition and selection).

Thus it may be said that the first requisite of a suitable Diesel lubricant should be its ability to burn clean in the cylinders and that when exposed to pressure, temperature, and destructive effects of the byproducts of combustion its chemical composition should not change so as to make it responsible for excessive deposits in or around the piston rings, or through the combustion chamber.

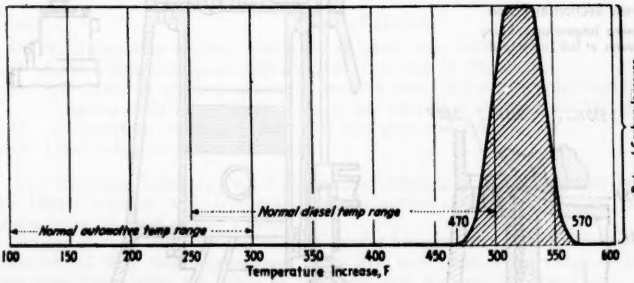


Fig. 4—Theoretical critical temperature of carbon formation for a chemically unsuitable type of lubricating oil

Some types of lubricating oils, particularly those recognized as outstanding in the automotive field, do not fit Diesel service because of their tendency to throw down hard lacquer-like carbon deposits within a critical range of temperature. Small, high-speed, mobile-type Diesels are more difficult to lubricate from the standpoint of ring sticking than larger, slower-speed stationary engines. Figure 3 lists temperatures existing at various points of the combustion-chamber envelope of a pre-combustion-chamber engine. Figure 4 shows the critical temperature range (470 F. to 570 F.) in which one particular lubricating oil tested had a tendency to throw down excessive amounts of carbon. The temperature of the upper piston-rings of the engine illustrated in Figure 3 falls right into this range. Obviously to secure satisfactory performance from the standpoint of minimizing ring deposits in this temperature range, it is necessary to use another lubricant which does not reach a peak of carbon formation within the critical temperatures at which the piston rings operate.

RING STICKING.

We can study ring sticking more accurately by dividing the contributing causes into two separate classes, see Figure 5. On the left side, we see a hard lacquer-like deposit formed when decomposition of the lubricating oil begins. This hard film is formed when the piston is hot. Upon shutting down, aluminum pistons radiate their heat quickly and inasmuch as clearance in the ring grooves is small, the vertical contraction in the groove, which amounts to less than 0.001 inch, will tend to seize the lacquer film and clasp the ring in its groove. This clamping does not necessarily take place over the entire ring surface, but may be localized in limited regions only. Following this action, radial contraction of the piston continues and in the case of a piston 5¾ inches in diameter, the contraction may amount to as much as 0.020 inch. Thus the ring is drawn away from the cylinder wall and the gap formed by this action makes it impossible for the ring to follow the contour of the cylinder liner, and blowby results. The hot gases of compression and combustion sweep the lubricating oil film from the cylinder wall, producing loss of compression, abrasion, high localized temperatures, rapid wear, and, in severe cases, piston seizure.

CARBON FORMATION.

The right side of Figure 5 illustrates another type of ring sticking. In this case, hard granular carbon begins to form at the back corner of the top ring and accumulates between the ring and the piston contour. As carbon continues to form in this area it is packed in back of the ring by its reciprocating motion as it works in and out, following the cylinder wall. The ring soon becomes completely restricted in its movement and rides constantly against the liner. This means that there can be no flexible flow of the ring surface with the contour of the cylinder wall and there is great danger of rupture of the oil film.

Experience in the lubrication of pre-combustion-chamber Diesels and other designs more sensitive to carbon formation has seemed to favor the naphthenic type of lubricating oil, up to the present. However, recent developments have brought to light oustanding addition agents for correctly refined paraffinic lubricating oils, making this class highly suitable for Diesel lubrication. In addition to preventing the formation of hard, lacquer-like, carbon-

TABLE II—PUMPABILITY OF DIESEL FUELS

Low Temperature Limit for Satisfactory Handling	*Approximate Viscosity, Saybolt sec. at 100 F.*
—20 F	42
0	50
20	65
40	98
60	160

(Paraffinic Type)

Pour Point	*Low Temperature Limit for Satisfactory Handling*	*Approximate Viscosity, Saybolt sec. at 100 F.*
—30 F	—20 F	32
0	10	38
30	40	42

(Naphthenic Type)

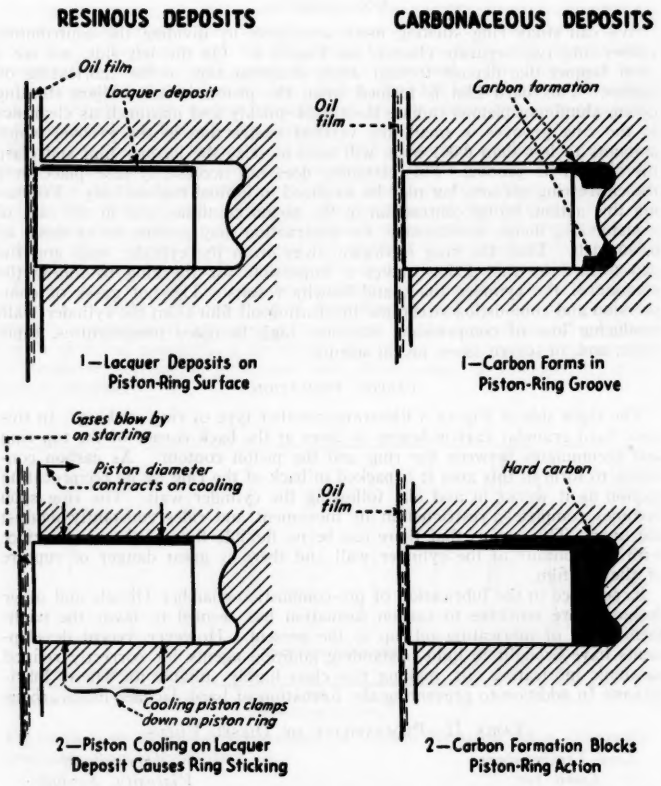


Fig. 5—How resinous and carbonaceous deposits produce ring sticking

aceous deposits in the combustion chamber and around the upper piston rings, these addition agents in correctly refined paraffinic oils increase the film-strength characteristics and inhibit oxidation in the crankcase.

Engineers who desire to operate their plants at the lowest possible cost should carefully consider the chemical stability of the crankcase oil. The oil should resist to the highest degree the effect of oxidation. Oxidation is responsible for the formation of organic acids in the oil, which, if allowed to become sufficiently concentrated, may be the cause of bearing corrosion and failure. In addition, if the lubricating oil is not highly chemically stable, excessive amounts of sludge form, which accumulate throughout the drilled passages of the crankshaft, connecting rods, and circulatory system. Such sticky sludges also have a tendency to accumulate over oil screens and on oil cooler surfaces, a threat to the entire engine.

In summarizing these remarks about lubricating oil, it cannot be too strongly emphasized that an oil's performance, both in the cylinders and in the crankcase, is related to its chemical characteristics. Since oil is a complex chemical compound, no laboratory can predict its actual performance value in an engine, based on laboratory evaluation alone. The only actual proof of a lubricating oil's suitability for Diesel-engine service lies in knowledge of what the oil will actually do in such an engine. The wise operator will be guided by the experience of reputable companies who have a sufficiently large staff of lubricating engineers in the field to study constantly performance characteristics of various types of lubricants, and laboratory and refinery technicians to coordinate this data.

Viscosity constitutes the one important physical characteristic of a lubricating oil for Diesel service (we have given oil stability from the standpoint of resistance to ring sticking and crankcase deposits first consideration, because this chemical stability is so exceptionally important in keeping down maintenance cost). The operator can look to the engine builder as the most reliable authority for the proper viscosity of oil.

BOOK REVIEW.

THE RADIO AMATEUR'S HANDBOOK, EIGHTEENTH (1941) EDITION, BY THE HEADQUARTERS STAFF OF THE A. R. R. L. REVIEWED BY LT. COMMANDER A. L. BECKER, U. S. N.

The 32 chapters, comprising 552 pages, in this new Handbook constitute a complete exposition of practical amateur operating and constructional data. It contains approximately 830 illustrations and 90 charts and tables. One chapter is devoted almost entirely to vacuum tubes, and the tables of tube characteristics make up probably the most complete single compilation of vacuum-tube data published, covering some 700 types.

There are two introductory chapters followed by four chapters on the principles and theories of radio reception and transmission. The next fourteen chapters present discussions and descriptions of the construction and adjustment of receivers, transmitters, power supplies, modulators, keying devices, measuring equipment, portable radio gear, and various other pieces of radio apparatus.

The antenna section consists of five chapters covering the field of antenna fundamentals, R. F. transmission lines, long wire antennae, multi-element directive systems and antenna construction. The ultra-high frequency section, also, contains five chapters. Basic principles are considered followed with circuits and constructional data for ultra-high frequency receivers, transmitters and antennae of reliable and sound design, instead of novel and eccentric circuits.

The last two chapters include information for operating the radio station and the rules and regulations of the F. C. C. pertaining to amateur radio communications. The last 90 pages of the handbook make up the catalog section, wherein data and specifications concerning the products of approved supplies of amateur gear are conveniently supplied.

The A. R. R. L. Handbook has the experience and skill developed by its 17 predecessors incorporated into it, and it should very efficiently and effectively fulfill the purposes of a text, reference book and practical operating manual. Price, paper bound, $1.00 in continental U. S. A., $1.50 elsewhere; buckram bound, $2.50. Spanish edition, $1.50.

ASSOCIATION NOTES.

OFFICERS FOR 1941.

The following were elected officers of the Society for 1941:

President:
Captain Claud A. Jones, U. S. N.

Secretary-Treasurer:
Commander J. E. Hamilton, U. S. N.

Council:
Captain Edward L. Cochrane, U. S. N.
Commander Louis Dreller, U. S. N.
Commander Thomas J. Bay, U. S. N.
Commander Ellis Reed-Hill, U. S. C. G.
Mr. W. S. Newell.
Mr. George W. Codrington.
Mr. W. E. Blewett, Jr.

AMENDMENTS TO BY-LAWS.

The amendments to the By-Laws which were presented to the membership at the time of the election were all adopted and became effective as of January 1, 1941.

VACANCY IN COUNCIL.

At a meeting of the Council on January 9, 1941, Commander Louis Dreller, U. S. N., resigned as a member of the Council due to detachment from the Bureau of Ships. Commander N. L. Rawlings, U. S. N., was appointed to the Council to fill the unexpired term of Commander Dreller.

ANNUAL BANQUET.

The date of the annual banquet has been set for April 25, 1941. With the approval of the Council the following banquet committee has been appointed:

It is with sincere regret that the Society notes the death on 12 February, 1941, of Rear Admiral HUTCH I. CONE, U. S. Navy, retired. Admiral Cone was a member of the Society from January, 1902, until his death. He was its President in 1910 and 1911, since which time he has been an Honorary member.

Commander E. E. Brady, U. S. N.
Commander L. F. Small, U. S. N.
Commander J. E. Hamilton, U. S. N.
Lieut. Commander E. H. Thiele, U. S. C. G.
Mr. Harold K. Beck.

The usual banquet notice and reservation blanks will be mailed very shortly.

SOCIETY LAPEL BUTTONS.

The order blank for lapel buttons is republished in this issue. These buttons, which were originally announced in the November, 1940, issue, are being sold to members for fifty cents each, postpaid.

NEW MEMBERS.

The following have joined the Society since the publication of the November, 1940, JOURNAL:

NAVAL.

Anderson, E. A., Lieutenant, U. S. C. G.

Bacher, E. J., RCA Mfg. Co., Inc., 201 North Front St., Camden, N. J.

Barnes, Arthur D., Lieut. Commander, U. S. N.

Becton, Sterling, Lieut. U. S. N. R., Guarantee Engineer, Sun Shipbuilding and Dry Dock Co. Residence, 909 Upland Ave., Chester, Pa.

Bennett, Bradley F., Lieutenant, U. S. N.

Berry, Earle W., Lieut. Commander, U. S. N. R., care Office of Inspector of Naval Material, 1600 Arch St., Philadelphia, Pa.

Bowen, H. G., Jr., Lieutenant, U. S. N.

Brown, T. T., Lieutenant, U. S. N. R., Bureau of Ships, Navy Dept., Washington, D. C.

Campbell, Clarence H., Lieutenant, U. S. N. R., Bureau of Ships, Navy Dept. Residence, Andrew Jackson House, Presidential Gardens, Alexandria, Va.

Cascini, Ernest, Lieutenant (j.g.), U. S. C. G.

Cooper, Howard L., Lieut. Commander, U. S. N. R., Bureau of Ships, Navy Dept. Residence, 102 W. Bellefonte Ave., Alexandria, Va.

Coulter, Ernest B., Lieutenant (j.g), U. S. N. R., Bureau of Ships, Navy Dept. Residence, 3109 Columbia Pike, Arlington, Va.

Dunning, Allan L., Lieutenant, U. S. N.

Ela, D. K., Ensign, U. S. N.

Fairbank, J. E., Lieutenant, U. S. C. G.

Fraunenfelder, J. Barraja, Lieut. Commander, U. S. N. R., Swarthmore, Pa.

Gibson, P. F., Sales Engineer, Marine Division, Lidgerwood Mfg. Co., 23 W. 10th St., New York, N. Y.

Giffin, Alvin H., Lieutenant, U. S. C. G.

Grimes, C. G., Lieut. Commander, U. S. N.

Haugen, Lawrence T., Commander, U. S. N.

Heiser, H. M., Lieutenant, U. S. N.

Holtz, E. W., Lieutenant, U. S. C. G.

Jones, Frank C., Ensign, U. S. N.

Kniskern, H. P., Jr., Ensign, U. S. C. G.

Lafore, Robert W., Lieutenant, U. S. N. R., 10 Rose Hill Road, Moylan, Pa.

Little, Harold H., Lieut. Commander, U. S. N., Ret., Bureau of Ships, Navy Department. Residence, R. D. 2, St. Margarets, Annapolis, Md.

Loewus, J. L., Lieutenant, U. S. C. G.

Lowith, C. W., Lieutenant (j. g.), U. S. N. R., U. S. S. *Cuyama*.

Lowrey, B. G., Lieutenant, U. S. N.

Lucas, R. L., Commander, U. S. C. G.

Mansfield, William N., Lieutenant Commander, U. S. N. R., Room 1712, Navy Department, Washington, D. C.

Myers, O. W., Machinist, U. S. N.

Norton, Gardner A., Lieutenant, U. S. N. R., 42 Laurel Road, Chestnut Hill, Mass.

Reifel, William M., Commander, U. S. N., Ret., Bureau of Ships, Navy Department. Residence, Kensington, Md.

Riggs, Carl O., Jr., Ensign, U. S. N. R., 323 Fairfax Ave., Norfolk, Va.

Ross, R. M., Lieutenant, U. S. C. G.

Shoemaker, B. D., Ensign, U. S. C. G.

Simmers, C. M., Captain, U. S. N.

Sternfelt, Carl W., Lieutenant, U. S. N. R., 1 Carl Road, Arlington, Mass.

Sutherland, Robert T., Lieutenant, U. S. N.

Tomkiel, Frank, Lieut. Commander, U. S. C. G.

Tooke, Charles M., Lieutenant, U. S. N.

Vishnesky, E. J., Machinist, U. S. N.

Wallin, Homer N., Commander, U. S. N.

Watson, Paul G., Lieutenant, U. S. N. R., 27 Price St., West Chester, Pa.

Williams, Elmo H., Lieut. Commander, U. S. N., Ret., Office of Inspector of Naval Material, 600 Bryant St., San Francisco, Calif.

CIVIL.

Beeson, Kenneth H., P. O. Box 1485, Vallejo, Calif.

Carter, E. Robert, Chief of Engineering, The Fafnir Bearing Company, New Britain, Conn.

Clark, P. W., in charge Floating Equipment, U. S. Public Health Service, Washington, D. C. Residence, 612 St. Andrews Lane, Silver Spring, Md.

Clinedinst, Wendell W., Engineer, C. H. Wheeler Mfg. Co., 233 Broadway, New York, N. Y.

Clingman, Palmer, Chief Engineer, McNab of Bridgeport, Inc., Bridgeport, Conn.

Dodge, Horace E., President, Dodge Boat & Plane Corporation, 420 Park Ave., New York, N. Y.

Dutton, Watson P., Sales Engineer, RCA Mfg. Co., Washington, D. C. Residence, 3114 Fifth St., N., Arlington, Va.

Ferman, W. E., Naval Architect, General Motors Laboratory, Detroit, Mich.

Harrison, W. L., Senior Engineer, Bureau of Ships, Navy Department. Residence, 2852 Ontario Road, N. W., Washington, D. C.

Kauffman, Erman R., Marine Engineer, Technical Division, Performance Section, U. S. Maritime Commission, Washington, D. C. Residence, 39 McKinley Ave., Hyattsville, Md.

Long, G. Allison, Assistant to Illuminating Engineer, Consolidated Gas & Electric Co., 452 Lexington Building, Baltimore, Md.

Love, J. E., RCA Manufacturing Co., Camden, N. J.

Mattucci, George A., Supervising Engineer, Marine Work, Babcock & Wilcox Co., 85 Liberty St., New York, N. Y.

Maxim, Hiram H., Chief Engineer, The Maxim Silencer Co., 85 Homestead Ave., Hartford, Conn.

Millard, M. D. V., U. S. Steel Corporation, Normandy Building, Washington, D. C.

Moore, Wesley B., Manager, General Diesel Sales, Fairbanks, Morse & Co., 600 S. Michigan Ave., Chicago, Ill.

Nelson, James J., 159 W. Tulpehocken St., Philadelphia, Pa.

Nettel, Frederick, Apartment 319, 720 West End Ave., New York, N. Y.

Rados, John, President, Harbor Boat Building Co., 1811 Patton Ave., San Pedro, Calif.

Richardson, Richard B., P. O. Box 248, Pompton Plains, N. J.

Sutphen, Henry R., Vice President, Electric Boat Co., 40 Wall St., New York, N. Y.

Towne, Selwyn H., Jr., Chief Engineer, Bath Iron Works Corp., Bath, Me.

Umland, Walter M., Senior Engineer, Navy Yard, New York, N. Y. Residence, 9412 214th St., Queens Village, N. Y.

Wiebel, Arthur J., Assistant to Vice President, Engineering, U. S. Steel Corp. of Delaware. Residence, 741 Jefferson Drive, North Hills Estates, Pittsburgh, (2) Pa.

Wood, Joseph Kaye, Chief Engineer, General Spring Corporation, 11 W. 42nd St., New York, N. Y.

ASSOCIATE.

Asp, Howard L., Sales Engineer, Crane Packing Co., 259 Second St., San Francisco, Calif.

Butt, Harvey R., care Lieut. Commander Wm. H. Mansfield, U. S. N. R., 6132 30th St., N. W., Washington, D. C.

Cowling, James G., Special Representative, Allegheny Ludlum Steel Corp., Pittsburgh, Pa. Residence, 1001 15th St., N. W., Washington, D. C.

Curtis, W. F., D. W. Taylor Model Basin, Navy Department, Washington, D. C.

Dennison, Boyd C., Jr., Assistant Engineer, Turbine and Gear Section, Bureau of Ships, Navy Department, Washington, D. C.

Horn, W. M., General Sales Manager, Bendix Aviation Corp., 754 Lexington Ave., Brooklyn, N. Y.

Jameson, W. S., Commander (E) R. N., British Embassy, Washington, D. C.

Kane, S. A., Assistant Engineer, Turbine and Gear Section, Bureau of Ships, Navy Department, Washington, D. C.

Lynn, George H., Manufacturers' Representative, 208 Munsey Building, Washington, D. C.

Metzgar, J. H., care Ingersoll-Rand Co., 1627 K St., N. W., Washington, D. C.

Moore, A. H., 609 Barr Building, Washington, D. C.

Oldham, P. T., By-Products Steel Corp., Coatsville, Pa. Residence, E. First Ave., Parkesburg, Pa.

Soutter, Robert, Room 550, Munsey Building, Washington, D. C.

Stanley, Charles F., Vice President and General Sales Manager, Fafnir Bearing Co., New Britain, Conn.

Stille, F. C., Special Representative, Ordnance National Tube Co.. 410 Normandy Building, Washington, D. C.

TRANSFERRED ASSOCIATE TO CIVIL.

Norton, Theodore E., Bureau of Ships, Navy Department, Washington, D. C.